



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : C07D 241/04, 401/12, 279/12, 265/30, 417/12, A61K 31/44, 31/50, 31/54, 31/535	A1	(11) International Publication Number: WO 97/20824 (43) International Publication Date: 12 June 1997 (12.06.97)
(21) International Application Number: PCT/US96/19328 (22) International Filing Date: 5 December 1996 (05.12.96) (30) Priority Data: 08/569,766 8 December 1995 (08.12.95) US (60) Parent Application or Grant (63) Related by Continuation US 08/569,766 (CIP) Filed on 8 December 1995 (08.12.95) (71) Applicant (for all designated States except US): AGOURON PHARMACEUTICALS, INC. [US/US]; 10350 N. Torrey Pines Road, La Jolla, CA 92037-1020 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): ZOOK, Scott, E. [US/US]; 14029-A Mango Drive, Del Mar, CA 92014 (US). DAGNINO, Raymond, Jr. [US/US]; 11365 Surco Drive, San Diego, CA 92126 (US). DEASON, Michael, E. [US/US]; 13826 Frame Road, Poway, CA 92064 (US). BENDER, Steven, L. [US/US]; 3884 Mount Abraham Avenue, San Diego, CA 92111 (US). MELNICK, Michael,		J. [US/US]; 6705 Forum Street, San Diego, CA 92111 (US). (74) Agents: GARRETT, Arthur, S. et al.; Finnegan, Henderson, Farabow, Garrett & Dunner, L.L.P., 1300 I Street, N.W., Washington, DC 20005-3315 (US). (81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the</i> <i>claims and to be republished in the event of the receipt of</i> <i>amendments.</i>
(54) Title: METALLOPROTEINASE INHIBITORS, PHARMACEUTICAL COMPOSITIONS CONTAINING THEM AND THEIR PHARMACEUTICAL USES, AND METHODS AND INTERMEDIATES USEFUL FOR THEIR PREPARATION		
(57) Abstract <p>The invention relates to compounds of formula (1) wherein: Z is O or S; V is a divalent radical which together with C* and N forms a ring having six ring atoms, where each of said ring atoms other than C* and N independently is unsubstituted or substituted by a suitable substituent, and at least one of said other ring atoms is a heteroatom selected from O, N and S, and the remainder is carbon atoms; and Ar is an aryl or heteroaryl group; and pharmaceutically acceptable prodrugs, salts and solvates thereof. The invention further relates to pharmaceutically acceptable prodrugs, salts and solvates of these compounds. The invention also relates to methods of inhibiting the activity of metalloproteinases by administering a compound of formula (1) or a prodrug, salt or solvate thereof. The invention further relates to pharmaceutical compositions comprising an effective amount of these compounds, prodrugs, salts, and solvates. The invention still further relates to methods and intermediates useful for preparing these compounds, prodrugs, salts, and solvates.</p> <div style="text-align: center;"> <p>(1)</p> </div> <div style="text-align: right; margin-top: 20px;"> <p>EV 311408213 US</p> </div>		

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgyzstan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	KZ	Kazakhstan	SG	Singapore
CH	Switzerland	LI	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovakia
CM	Cameroon	LR	Liberia	SN	Senegal
CN	China	LT	Lithuania	SZ	Swaziland
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	LV	Latvia	TG	Togo
DE	Germany	MC	Monaco	TJ	Tajikistan
DK	Denmark	MD	Republic of Moldova	TT	Trinidad and Tobago
EE	Estonia	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	UG	Uganda
FI	Finland	MN	Mongolia	US	United States of America
FR	France	MR	Mauritania	UZ	Uzbekistan
GA	Gabon			VN	Viet Nam

- 1 -

Description

METALLOPROTEINASE INHIBITORS,
PHARMACEUTICAL COMPOSITIONS CONTAINING
THEM AND THEIR PHARMACEUTICAL USES,
AND METHODS AND INTERMEDIATES USEFUL
FOR THEIR PREPARATION

The present invention relates to compounds that inhibit metalloproteinases, particularly matrix metalloproteinases and tumor necrosis factor- α convertase, and their pharmaceutically acceptable salts and pharmaceutically acceptable prodrugs. The invention further relates to the uses of these compounds, salts and prodrugs for the therapeutic treatment of humans or animals.

Matrix metalloproteinases ("MMPs") are a family of enzymes, including, but not limited to, collagenases, gelatinases, matrilysin, and stromelysins, which are involved in the degradation and remodelling of connective tissues. These enzymes are found in a number of cell types that are found in or associated with connective tissue, such as fibroblasts, monocytes, macrophages, endothelial cells and metastatic tumor cells. They also share a number of properties, including zinc and calcium dependence, secretion as zymogens, and 40-50% amino acid sequence homology.

Matrix metalloproteinases degrade the protein components of the extracellular matrix, i.e. the protein components found in the linings of joints, interstitial connective tissue, basement membranes, cartilage and the like. These proteins include collagen, proteoglycan, fibronectin and laminin.

Collagen is the major structural protein of mammalian tissue, comprising one-third of the total protein in mammalian organisms, and is an essential component of many matrix tissues, including cartilage, bone, tendons and skin. Interstitial collagenases catalyze the initial (rate-limiting) cleavage of native collagen types I, II, III and X. These enzymes cleave collagen into two fragments which spontaneously denature at physiological temperature. Denaturation of collagen involves conversion of the rigidly coiled helix to a random coil referred to as gelatin. These gelatin (denatured

- 2 -

collagen) fragments are then subject to further cleavage and degradation by less specific enzymes. The net result of collagenase cleavage is thus the loss of structural integrity in the matrix tissue (collagen collapse), an essentially irreversible process.

The gelatinases include two distinct yet highly related enzymes: a 72-kiloDalton (kDa) enzyme and a 92-kiloDalton enzyme. The former is released by fibroblasts while the latter is released by mononuclear phagocytes, neutrophils, corneal epithelial cells, tumor cells, cytotrophoblasts and keratinocytes. Both enzymes degrade gelatins (denatured collagens), collagen types IV (basement membrane) and V, fibronectins (high molecular weight multifunctional glycoproteins found in soft connective tissue and basement membranes) and insoluble elastin (highly cross-linked hydrophobic proteins found in load bearing fibers of mammalian connective tissue).

Stromelysins (1 and 2) cleave a broad range of matrix substrates, including laminin, fibronectins, proteoglycans and collagen types IV and IX (non-helical).

Matrilysin (putative metalloproteinase or PUMP) also degrades a wide variety of matrix substrates, including proteoglycans, gelatins, fibronectins, elastins and laminin. Matrilysin has been found in mononuclear phagocytes, rat uterine explants and tumor cells.

In normal tissues, the activity of matrix metalloproteinases is tightly regulated. As a result, the breakdown of connective tissue mediated by these enzymes is generally in a dynamic equilibrium with synthesis of new matrix tissue.

In a number of pathological disease conditions, however, deregulation of matrix metalloproteinase activity leads to the uncontrolled breakdown of extracellular matrix. These disease conditions include arthritis (e.g., rheumatoid arthritis and osteoarthritis), periodontal disease, aberrant angiogenesis, tumor metastasis and invasion, tissue ulceration (e.g., corneal ulceration, gastric ulceration or epidermal ulceration), bone disease, HIV-infection and complications from diabetes.

Administration of matrix metalloproteinase inhibitors has been found to reduce the rate of connective tissue degradation, thereby leading to a favorable therapeutic effect. For example, in *Cancer Res.*, vol. 53, p. 2087 (1993), a synthetic matrix metalloproteinase inhibitor was shown to have *in vivo* efficacy in a murine model for ovarian cancer with an apparent mode of action consistent with inhibition of matrix remodelling. The design and uses of MMP inhibitors are reviewed, for example, in *J. Enzyme Inhibition*, 2, 1-22 (1987); *Progress in Medicinal Chemistry* 29, 271-334 (1992); *Current Medicinal Chemistry*, 2, 743-762 (1995); *Exp. Opin. Ther. Patents*, 5, 1287-1296 (1995); and *Drug Discovery Today*, 1, 16-26 (1996).

Matrix metalloproteinase inhibitors are also the subject of numerous patents and patent applications, including: U.S. Patent No. 5,189,178; U.S. Patent No. 5,183,900; U.S. Patent No. 5,506,242; U.S. Patent No. 5,552,419; U.S. Patent No. 5,455,258; European Patent Application No. 0 438 223; European Patent Application No. 0 276 436; WIPO International Publication No. WO 92/21360; WIPO International Publication No. WO 92/06966; WIPO International Publication No. WO 92/09563; WIPO International Publication No. WO 96/00214; WIPO International Publication No. 95/35276; and WIPO International Publication No. WO 96/27583, the disclosures of each of which are incorporated herein by reference.

Tumor necrosis factor- α ("TNF- α ") is a cytokine which is produced as a 28-kDa precursor and released in an active 17-kDa form. This active form can mediate a large number of deleterious effects *in vivo*, including inflammation, fever, cardiovascular effects, haemorrhage, coagulation and acute phase responses, similar to those seen during acute infections and shock states. Chronic administration of TNF- α can cause cachexia and anorexia; accumulation of excess of TNF- α can be fatal.

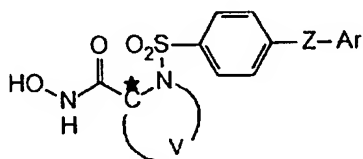
TNF- α convertase is a metalloproteinase involved in the biosynthesis of TNF- α . Inhibition of TNF- α convertase inhibits production of TNF- α .

- 4 -

Since excessive TNF- α production has been noted in several disease conditions characterized by MMP-mediated tissue degradation, including multiple sclerosis, arthritis and cancer, compounds which inhibit both MMPs and TNF- α convertase are especially advantageous for the treatment or prophylaxis of disease conditions in which both mechanisms are involved. Although compounds that both inhibit MMPs activity and TNF- α production have been disclosed in WIPO International Publication Nos. WO 94/24140 and WO 94/02466, the disclosures of which are herein incorporated by reference, there is still a need for effective MMP and/or TNF- α convertase inhibiting agents.

Because of their beneficial therapeutic effects, there is a need for effective inhibitors of metalloproteinase activity. The present invention is therefore directed to certain compounds that inhibit metalloproteinases, such as MMPs and TNF- α convertase, their pharmaceutically acceptable prodrugs, salts and solvates, pharmaceutical compositions containing the same and methods of using the same, as well as to method and intermediates useful in their preparation. Additional features and advantages of the invention will be set forth in the description which follows, and in part will be apparent from the description or may be learned from practice of the invention.

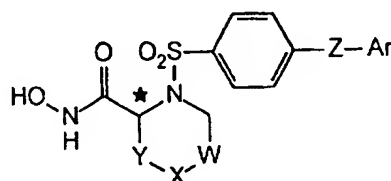
To achieve these and other advantages, the present invention provides a compound of formula 1:



wherein Z is O or S; V is a divalent radical which together with C* and N forms a ring having six ring atoms, where each of said ring atoms other than C* and N independently is unsubstituted or substituted by a suitable substituent, and at least one of said other ring atoms is a heteroatom selected from O, N and S, and the remainder are carbon atoms; and Ar is an aryl or heteroaryl group; or a pharmaceutically acceptable prodrug, salt or solvate thereof.

- 5 -

Preferred compounds of the formula 1 include those having the formula 1-a:



wherein

W, X and Y are each, independently of one another, CR_1R_2 , $C=O$, S, $S=O$, SO_2 , O, $N-R_3$, or $N^+(O^-)-R_4$, where

R_1 and R_2 are independently selected from H and a suitable organic moiety, or wherein R_1 and R_2 together form a cycloalkyl group or a heterocycloalkyl group,

R_3 is hydrogen or a suitable organic moiety, and

R_4 is an alkyl group,

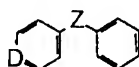
with the proviso that at least one, but not all, of W, X, and Y are selected from CR_1R_2 and $C=O$,

or a pharmaceutically acceptable prodrug, salt, or solvate thereof.

The invention is also directed to a method of inhibiting the activity of a metalloproteinase, such as an MMP or TNF- α convertase, by administering a compound of the formula 1 or 1-a, or a pharmaceutically acceptable prodrug, salt or solvate thereof. The invention is further directed to a pharmaceutical composition comprising an effective amount of a compound of the formula 1 or 1-a or a pharmaceutically acceptable prodrug, salt or solvate thereof.

The invention is still further directed to a method for making compounds of the formula 1 or 1-a involving one or more reactions as follows, wherein the variables in the formulas below are defined beginning at page 11:

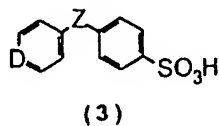
(1) converting a compound of formula 2:



(2)

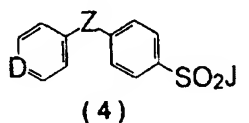
- 6 -

or a salt or solvate thereof, to a compound of formula 3:



or a salt or solvate thereof, under conditions sufficient to form a compound of formula 3;

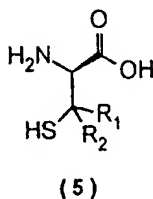
(2) converting a compound of formula 3 above, or a salt or solvate thereof, to a compound of formula 4:



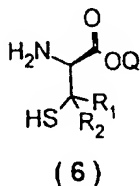
or a salt or solvate thereof, under conditions sufficient to form a compound of formula 4, or a salt or solvate thereof;

(3) converting a compound of formula 2 above, or a salt or solvate thereof, to a compound of formula 4 above, or a salt or solvate thereof, under conditions sufficient to form a compound of formula 4, or a salt or solvate thereof;

(4) converting a compound of formula 5:



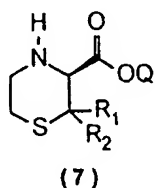
or a salt or solvate thereof, to a compound of formula 6:



or a salt or solvate thereof, under conditions sufficient to form a compound of formula 6, or a salt or solvate thereof;

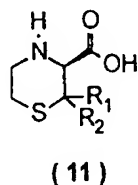
- 7 -

(5) converting a compound of formula 6 above, or a salt or solvate thereof, to a compound of formula 7:



or a salt or solvate thereof, under conditions sufficient to form a compound of formula 7, or a salt or solvate thereof;

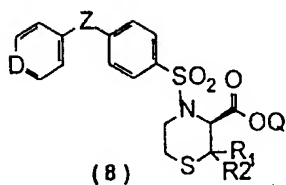
(6) converting a compound of formula 11:



or a salt or solvate thereof, to a compound of formula 7 above, or a salt or solvate thereof, under conditions sufficient to form said compound of formula 7, or a salt or solvate thereof;

(7) converting a compound of formula 5 above, or a salt or solvate thereof, to a compound of formula 11 above, or a salt or solvate thereof, under conditions sufficient to form said compound of formula 11, or a salt or solvate thereof;

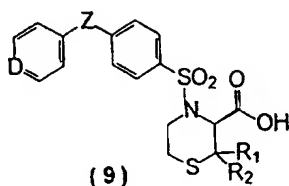
(8) reacting a compound of formula 7 above, or a salt or solvate thereof, or a compound of formula 11 above, or a salt or solvate thereof, with a compound of formula 4 above, or a salt or solvate thereof, under conditions sufficient to form a compound of formula 8:



or a salt or solvate thereof;

- 8 -

(9) converting a compound of formula 8 above, or a salt or solvate thereof, to a compound of formula 9:

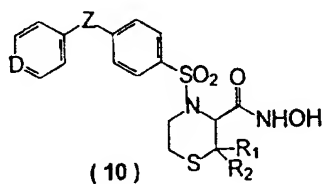


or a salt or solvate thereof, under conditions sufficient to form a compound of formula 9, or a salt or solvate thereof;

(10) converting a compound of formula 4 above, or a salt or solvate thereof, to a compound of formula 9 above, or a salt or solvate thereof, under conditions sufficient to form a compound of formula 9, or a salt or solvate thereof;

(11) converting a compound of formula 7 above, or a salt or solvate thereof, to a compound of formula 9 above, or a salt or solvate thereof, under conditions sufficient to form a compound of formula 9, or a salt or solvate thereof;

(12) converting a compound of formula 9 above, or a salt or solvate thereof, to a compound of formula 10:



or a salt or solvate thereof, under conditions sufficient to form a compound of formula 10, or a salt or solvate thereof; and

(13) converting a compound of formula 7 above, or a salt or solvate thereof, to a compound of formula 10 above, or a salt or solvate thereof, under conditions sufficient to form a compound of formula 10, or a salt or solvate thereof.

- 9 -

In the above-described conversions and reactions, the following definitions apply:

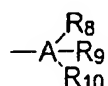
D is N or C-R₁₆, wherein R₁₆ is an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, or a heteroaryl group,

Z is O or S,

J is a halogen, 1,2,4-triazolyl, benzotriazolyl or imidazol-1-yl,

R₁ and R₂ are as defined above, and

Q is a cycloalkyl group, an aryl group, a heteroaryl group, a heterocycloalkyl group, or a group of formula

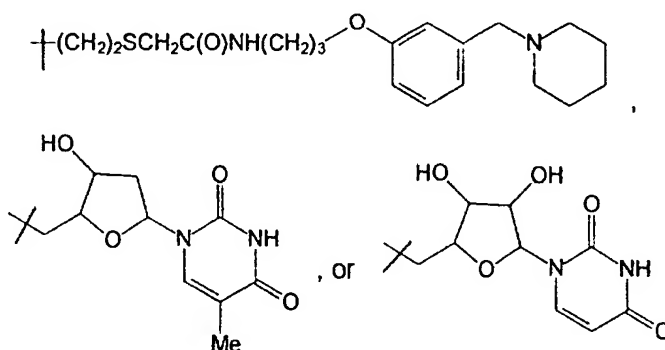


wherein A is C or Si, and R₈, R₉, and R₁₀ are independently selected from H and any suitable organic moiety, or a salt or solvate thereof,

with the provisos that:

for conversion (1) above, when D is C-R₁₆, R₁₆ is a heteroaryl group, and

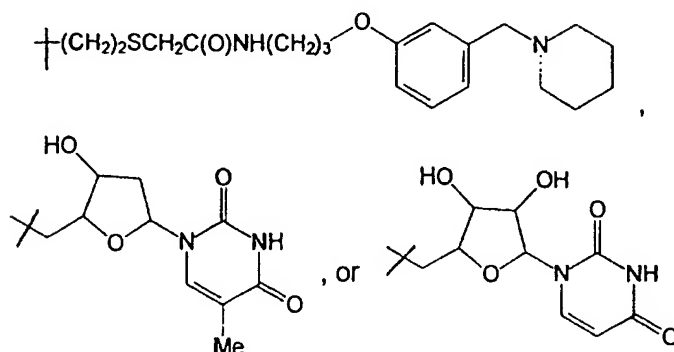
for conversion (4) above, the compound, salt or solvate of formula 6 is not a diester and Q is not methyl, ethyl, isopropyl, n-butyl, -CH₂-phenyl,



Additionally, the present invention is directed to compounds of formulas 3, 4, 6, 7, 8, and 9 above. For the compounds, salts and solvates of formula 3 above, when D is C-R₁₆, R₁₆ is a heteroaryl group. Further, the

- 10 -

compound, salt or solvate of formula 6 is not a diester. Additionally, for the compounds, salts, and solvates of formula 6, Q is not methyl, ethyl, isopropyl, n-butyl, -CH₂-phenyl,



Preferred embodiments of the above-identified compounds, compositions, and methods are discussed in more detail below following the definitions.

As used in the present application, the following definitions apply, unless otherwise indicated:

An "alkyl group" is intended to mean a straight or branched chain monovalent radical of saturated and/or unsaturated carbon atoms and hydrogen atoms, such as methyl, ethyl, propyl, isopropyl, butyl, isobutyl, t-butyl, ethenyl, pentenyl, butenyl, propenyl, ethynyl, butynyl, propynyl, pentynyl, hexynyl, and the like, which may be unsubstituted (i.e., containing only carbon and hydrogen) or substituted by one or more suitable substituents as defined below.

An "O-alkyl group" or "alkoxy group" is intended to mean an oxygen bonded to an alkyl group, wherein the alkyl group is as defined above.

A "cycloalkyl group" is intended to mean a non-aromatic, monovalent monocyclic, bicyclic, or tricyclic radical containing 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, or 14 carbon ring atoms, each of which may be saturated or unsaturated, and which may be unsubstituted or substituted by one or more suitable substituents as defined below, and to which may be fused one or more heterocycloalkyl groups, aryl groups, or heteroaryl groups, which themselves may be unsubstituted or substituted by one or more suitable

substituents. Illustrative examples of cycloalkyl groups include, but are not limited to, cyclopropyl, cyclobutyl, cyclopentyl, cyclopentenyl, cyclohexyl, cyclohexenyl, cycloheptyl, cyclooctyl, bicyclo[2.2.1]heptyl, bicyclo[2.2.1]hept-2-en-5-yl, bicyclo[2.2.2]octyl, bicyclo[3.2.1]nonyl, bicyclo[4.3.0]nonyl, bicyclo[4.4.0]decyl, indan-1-yl, indan-2-yl, tetralin-1-yl, tetralin-2-yl, adamantyl, and the like.

A "heterocycloalkyl group" is intended to mean a non-aromatic, monovalent monocyclic, bicyclic, or tricyclic radical, which is saturated or unsaturated, containing 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, or 18 ring atoms, and which includes 1, 2, 3, 4, or 5 heteroatoms selected from nitrogen, oxygen and sulfur, wherein the radical is unsubstituted or substituted by one or more suitable substituents as defined below, and to which may be fused one or more cycloalkyl groups, aryl groups, or heteroaryl groups, which themselves may be unsubstituted or substituted by one or more suitable substituents. Illustrative examples of heterocycloalkyl groups include, but are not limited to, azetidyl, pyrrolidyl, piperidyl, piperaziny, morpholinyl, tetrahydro-2H-1,4-thiazinyl, tetrahydrofuryl, dihydrofuryl, tetrahydropyranyl, dihydropyranyl, 1,3-dioxolanyl, 1,3-dioxanyl, 1,4-dioxanyl, 1,3-oxathiolanyl, 1,3-oxathianyl, 1,3-dithianyl, azabicyclo[3.2.1]octyl, azabicyclo[3.3.1]nonyl, azabicyclo[4.3.0]nonyl, oxabicyclo[2.2.1]heptyl, 1,5,9-triazacyclododecyl, and the like.

An "aryl group" is intended to mean an aromatic, monovalent monocyclic, bicyclic, or tricyclic radical containing 6, 10, 14, or 18 carbon ring atoms, which may be unsubstituted or substituted by one or more suitable substituents as defined below, and to which may be fused one or more cycloalkyl groups, heterocycloalkyl groups, or heteroaryl groups, which themselves may be unsubstituted or substituted by one or more suitable substituents. Illustrative examples of aryl groups include, but are not limited to, phenyl, naphthyl, fluoren-2-yl, indan-5-yl, and the like.

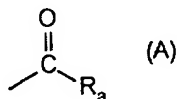
A "heteroaryl group" is intended to mean an aromatic monovalent monocyclic, bicyclic, or tricyclic radical containing 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, or 18 ring atoms, including 1, 2, 3, 4, or 5

heteroatoms selected from nitrogen, oxygen and sulfur, which may be unsubstituted or substituted by one or more suitable substituents as defined below, and to which may be fused one or more cycloalkyl groups, heterocycloalkyl groups, or aryl groups, which themselves may be unsubstituted or substituted by one or more suitable substituents. Illustrative examples of heteroaryl groups include, but are not limited to, pyrrolyl, imidazolyl, pyrazolyl, furyl, thienyl, thiazolyl, oxazolyl, isoxazolyl, isothiazolyl, oxadiazolyl, triazolyl, tetrazolyl, pyrazinyl, pyridyl, pyrimidyl, pyridazinyl, indolyl, isoindolyl, benzimidazolyl, benzofuryl, isobenzofuryl, benzothienyl, quinolyl, isoquinolyl, phthalazinyl, carbazolyl, purinyl, pteridiny, acridinyl, phenanthrolinyl, phenoxazinyl, phenothiazinyl, and the like.

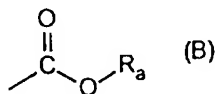
An "acyl group" is intended to mean a $-C(O)-R-$ radical, wherein R is any suitable substituent as defined below.

A "sulfonyl group" is intended to mean a $-S(O)(O)-R-$ radical, wherein R is any suitable substituent as defined below.

The term "suitable substituent" is intended to mean any of the substituents recognizable to those skilled in the art as not adversely affecting the inhibitory activity of the inventive compounds. Illustrative examples of suitable substituents include, but are not limited to, oxo groups, alkyl groups, hydroxy groups, halo groups, cyano groups, nitro groups, cycloalkyl groups, heterocycloalkyl groups, aryl groups, heteroaryl groups, trialkylsilyl groups, groups of formula (A)

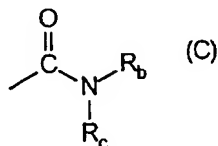


wherein R_a is hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, or a heteroaryl group, groups of formula (B)

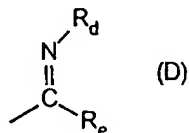


- 13 -

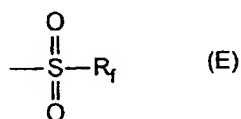
wherein R_a is hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, or a heteroaryl group,
groups of formula (C)



wherein R_b and R_c are independently hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, or a heteroaryl group,
groups of formula (D)



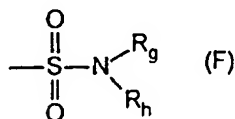
wherein R_d is hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, a hydroxy group, an alkoxy group, an amino group, an alkylamino group, a dialkylamino group, or an acylamino group; and R_e is hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, an amino group, an alkylamino group, or a dialkylamino group,
groups of formula (E)



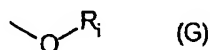
wherein R_f is an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, or a heteroaryl group,

- 14 -

groups of formula (F)

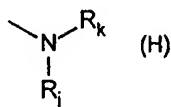


wherein R_g and R_h are independently hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, or a heteroaryl group,
groups of formula (G)

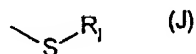


wherein R_i is an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, or a group of formula (A), formula (B), formula (C), formula (H), or formula (K),

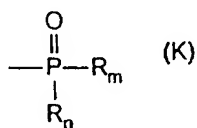
groups of formula (H)



wherein R_j is hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, a hydroxy group, an alkoxy group, an amino group, or a group of formula (A), formula (B), formula (C) or formula (D); and wherein R_k is hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, or a group of formula (A), formula (B), formula (C), formula (D), formula (E), or formula (F),
groups of formula (J)



wherein R_i is hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, or a group of formula (C), and
groups of formula (K)



wherein R_m and R_n are independently an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, a hydroxy group, an alkoxy group, an amino group, an alkylamino group, or a dialkylamino group.

The term "suitable organic moiety" is intended to mean any organic moiety recognizable to those skilled in the art as not adversely affecting the inhibitory activity of the inventive compounds. Illustrative examples of suitable organic moieties include, but are not limited to oxo groups, alkyl groups, hydroxy groups, halo groups, cyano groups, nitro groups, cycloalkyl groups, heterocycloalkyl groups, aryl groups, heteroaryl groups, trialkylsilyl groups, and groups of formulas (A), (B), (C), (D), (E), (F), (G), (H), (J), and (K), as defined above.

A "hydroxy group" is intended to mean the radical $-OH$.

An "oxo group" is intended to mean the divalent radical $=O$.

A "halo group" or is intended to mean any of the radicals $-F$, $-Cl$, $-Br$, or $-I$.

A "cyano group" is intended to mean the radical $-C\equiv N$.

A "nitro group" is intended to mean the radical $-NO_2$.

A "trialkylsilyl group" is intended to mean the radical $-SiR_pR_qR_s$, where R_p , R_q , and R_s are each independently an alkyl group.

A "carboxy group" is intended to mean a group of formula (B) wherein R_i is hydrogen.

A "alkoxycarbonyl group" is intended to mean a group of formula (B) wherein R_i is an alkyl group as defined above.

A "carbamoyl group" is intended to mean a group of formula (C) wherein R_i and R_j are both hydrogen.

An "amino group" is intended to mean the radical $-NH_2$.

An "alkylamino group" is intended to mean the radical $-NHR_u$, wherein R_u is an alkyl group as defined above.

A "dialkylamino group" is intended to mean the radical $-NR_uR_v$, wherein R_u and R_v , which are the same or different, are each an alkyl group as defined above.

- 16 -

A "pharmaceutically acceptable prodrug" is intended to mean a compound that is converted under physiological conditions or by solvolysis to a compound of the formula 1 or 1-a.

A "pharmaceutically acceptable solvate" is intended to mean a solvate that retains the biological effectiveness and properties of the biologically active components of compounds of formula 1 or 1-a.

Examples of pharmaceutically acceptable solvates include, but are not limited to, compounds of formula 1 or 1-a in combination with water, isopropanol, ethanol, methanol, DMSO, ethyl acetate, acetic acid, or ethanolamine.

In the case of solid formulations, it is understood that the inventive compounds may exist in different forms, such as stable and metastable crystalline forms and isotropic and amorphous forms, all of which are intended to be within the scope of the present invention.

A "pharmaceutically acceptable salt" is intended to mean those salts that retain the biological effectiveness and properties of the free acids and bases and that are not biologically or otherwise undesirable.

Examples of pharmaceutically acceptable salts include, but are not limited to, sulfates, pyrosulfates, bisulfates, sulfites, bisulfites, phosphates, monohydrogenphosphates, dihydrogenphosphates, metaphosphates, pyrophosphates, chlorides, bromides, iodides, acetates, propionates, decanoates, caprylates, acrylates, formates, isobutyrate, caproates, heptanoates, propiolates, oxalates, malonates, succinates, suberates, sebacates, fumarates, maleates, butyne-1,4-dioates, hexyne-1,6-dioates, benzoates, chlorobenzoates, methylbenzoates, dinitrobenzoates, hydroxybenzoates, methoxybenzoates, phthalates, sulfonates, xylenesulfonates, phenylacetates, phenylpropionates, phenylbutyrates, citrates, lactates, γ -hydroxybutyrates, glycolates, tartrates, methanesulfonates, propanesulfonates, naphthalene-1-sulfonates, naphthalene-2-sulfonates, and mandelates.

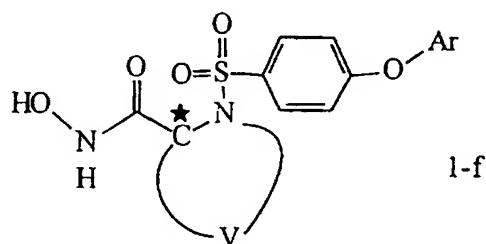
If the inventive compound is a base, the desired salt may be prepared by any suitable method known to the art, including treatment of the

- 17 -

free base with an inorganic acid, such as hydrochloric acid, hydrobromic acid, sulfuric acid, nitric acid, phosphoric acid and the like, or with an organic acid, such as acetic acid, maleic acid, succinic acid, mandelic acid, fumaric acid, malonic acid, pyruvic acid, oxalic acid, glycolic acid, salicylic acid, pyranosidyl acids such as glucuronic acid and galacturonic acid, alpha-hydroxy acids such as citric acid and tartaric acid, amino acids such as aspartic acid and glutamic acid, aromatic acids such as benzoic acid and cinnamic acid, sulfonic acids such as p-toluenesulfonic acid or ethanesulfonic acid, or the like.

If the inventive compound is an acid, the desired salt may be prepared by any suitable method known to the art, including treatment of the free acid with an inorganic or organic base, such as an amine (primary, secondary or tertiary), an alkali metal or alkaline earth metal hydroxide or the like. Illustrative examples of suitable salts include organic salts derived from amino acids such as glycine and arginine, ammonia, primary, secondary and tertiary amines, and cyclic amines such as piperidine, morpholine and piperazine, and inorganic salts derived from sodium, calcium, potassium, magnesium, manganese, iron, copper, zinc, aluminum and lithium.

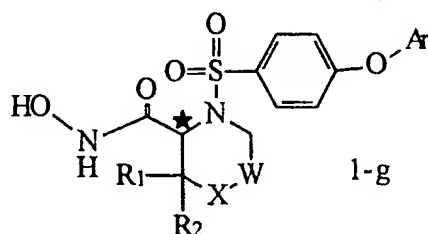
Additionally preferred is a compound of the formula 1-f:



wherein V is as defined above and Ar is a monocyclic aryl group or monocyclic heteroaryl group, or a pharmaceutically acceptable prodrug or a

- 18 -

pharmaceutically acceptable salt thereof. More preferred is a compound having the formula 1-g



wherein W and X are independently selected from CH₂, C=O, S, S=O, O, N-R₃, and N⁺(O⁻)-R₄, where R₃ is a hydrogen atom or a suitable substituent, and R₄ is a C₁-C₇ alkyl group, wherein the alkyl group is a straight or branched chain monovalent radical of carbon and hydrogen atoms having no unsaturation, which is optionally substituted by one or more suitable substituents, provided that when W is CH₂ or C=O, X is not CH₂ or C=O; and R₁ and R₂ are independently selected from a hydrogen atom, a C₁-C₇ alkyl group, a -C(O)OR₁₇ group, or a -C(O)NR₁₇R₁₈ group, wherein R₁₇ and R₁₈ are independently selected from hydrogen and an alkyl group, and wherein the alkyl group is a straight or branched chain monovalent radical of carbon and hydrogen atoms having no unsaturation, which is optionally substituted by one or more suitable substituents, or R₁ and R₂ together form a monocyclic cycloalkyl group or a monocyclic heterocycloalkyl group; or a pharmaceutically acceptable prodrug thereof or a pharmaceutically acceptable salt thereof.

Preferably, in the above formulas 1, 1-a, 1-f, and 1-g, Ar is a monocyclic aryl group or a monocyclic heteroaryl group. When Ar is a monocyclic aryl group, preferably it is unsubstituted or substituted at the meta position and/or the para position with a suitable substituent. Preferably, the substituent is a halogen atom, an aryl or heteroaryl group, an alkoxy group, or an alkyl group, wherein the alkyl group is a straight or branched chain monovalent radical of carbon and hydrogen atoms having no unsaturation, which is optionally substituted by one or more suitable substituents. Even more preferably, Ar is an aryl group that is substituted at the para position

- 19 -

with a halogen atom, an alkoxy group or a monocyclic heteroaryl group. Particularly preferred embodiments of the present invention include those where Ar is 4-fluorophenyl, 4-chlorophenyl, 4-methoxyphenyl 4-(imidazol-1-yl)phenyl or 4-(imidazol-2-yl)phenyl. Preferably when Ar is a monocyclic heteroaryl group, Ar is a pyrid-4-yl group.

In formula 1-a, preferably Y is CR_1R_2 , where R_1 and R_2 are independently selected from H and any suitable organic moiety. Preferably R_1 and R_2 are independently selected from H, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, OR_5 , SR_5 , NR_5R_6 , and $C(O)R_7$, where

R_5 is an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, or $C(O)NR_{13}R_{14}$,

where R_{13} and R_{14} are independently selected from H, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, and a heteroaryl group, or R_{13} and R_{14} , together with the nitrogen atom to which they are attached form a heterocycloalkyl group,

R_6 is H, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, $C(O)O-R_{15}$, $C(O)S-R_{15}$, or SO_2-R_{15} ,

wherein R_{15} is an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, or a heteroaryl group,

R_7 is OH, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, an O-alkyl group, $NR_{13}R_{14}$, or $O-R_{15}$, wherein R_{13} , R_{14} , and R_{15} are independently as defined above,

or R_1 and R_2 together form a cycloalkyl group or a heterocycloalkyl group.

More preferably R_1 and R_2 are each a methyl group.

In formulas 1-a and 1-g, preferably R_3 is hydrogen, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, $C(O)-NR_{13}R_{14}$, $C(O)-OR_{15}$, $C(O)-SR_{15}$, SO_2-R_{15} , or $C(O)-R_{13}$

- 20 -

where R_{13} and R_{14} are independently selected from H, an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, and a heteroaryl group, or R_{13} and R_{14} , together with the nitrogen atom to which they are attached form a heterocycloalkyl group, and

R_{15} is an alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, or a heteroaryl group.

Preferably, when W is CH_2 or $N-R_3$, X is S, $S=O$, O, $N-R_3$, $N^+(O)-R_4$ or $C=O$. More preferably, when W is CH_2 , X is O, $S=O$ or $N-R_3$, and R_3 is a suitable substituent, preferably a hydrogen atom, an alkyl group, wherein said alkyl group is a straight or branched chain monovalent radical of carbon and hydrogen atoms having no unsaturation, which is optionally substituted by one or more suitable substituents, a $C(O)-R_{17}$ group, a $C(O)O-R_{17}$ group, a $C(O)NH-R_{17}$ group, a $C(O)NR_{17}R_{18}$ group, an SO_2-R_{19} group, wherein R_{17} and R_{18} are each independently an alkyl group wherein said alkyl group is a straight or branched chain monovalent radical of carbon and hydrogen atoms having no unsaturation, which is optionally substituted by one or more suitable substituents, and wherein R_{19} is a monocyclic aryl group or an alkyl group as defined above. More preferably, R_3 is a hydrogen atom, a C_1-C_7 alkyl group, or a SO_2-R_{19} group, wherein R_{19} is an alkyl group. Most preferably, when W is CH_2 , X is O, S, $S=O$, $N-H$, $N-(SO_2CH_3)$ or $N-(C_1-C_7 \text{ alkyl})$.

Alternatively, when W is $N-R_3$, X is preferably $C=O$ and R_3 is preferably a hydrogen atom or an alkyl group, more preferably a hydrogen atom.

Particularly preferred embodiments of the present invention include those compounds of the formula 1-a and 1-g where X is S, $S=O$, O, $N-R_3$ or $N^+(O)-R_4$ and W is CH_2 ; or X is S, O or $N-R_3$ and W is $C=O$; or X is $C=O$ and W is $N-R_3$; or X is CH_2 and W is O, S or $N-R_3$, where R_3 is a $C(O)-R_{17}$ group, where R_{17} is as defined above. According to these preferred embodiments of the present invention, R_1 and R_2 are preferably, independently of one another, a hydrogen atom or a methyl group, and Ar is

preferably an aryl group which is unsubstituted or substituted in the para position with a suitable substituent, preferably a halogen atom, an alkoxy group or a heteroaryl group. More preferably, R_1 and R_2 are the same and Ar is an aryl group substituted in the para position with a fluorine atom, a chlorine atom, a methoxy group or an imidazolyl group.

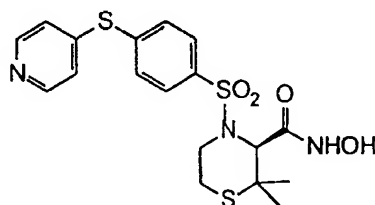
Illustrative examples of compounds according to these preferred embodiments of the present invention include, but are not limited to, 3(S)-N-hydroxy-2,2-dimethyl-4-(4-(4-(imidazol-2-yl)phenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide and 3(S)-N-hydroxy-2,2-dimethyl-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide.

Other preferred embodiments of the present invention include those compounds where Y is N- R_3 , where R_3 is a C(O)- R_{17} group, a C(O)O- R_{17} group, a C(O)NH- R_{17} group, a C(O)NR $_{17}$ R_{18} group, an SO $_2$ - R_{19} group, wherein R_{17} and R_{18} are each independently an alkyl group wherein said alkyl group is a straight or branched chain monovalent radical of carbon and hydrogen atoms having no unsaturation, which is optionally substituted by one or more suitable substituents, and wherein R_{19} is a monocyclic aryl group or an aryl group as defined above.

Also, according to the preferred embodiments of the present invention where X is N- R_3 , R_3 is a hydrogen atom, an alkyl group or an alkylsulfonyl group, more preferably a hydrogen atom, a methyl group or a methanesulfonyl group. Illustrative examples of compounds according to these preferred embodiments of the present invention include, but are not limited to, (R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide, (R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide, (R)-N-hydroxy-1-(4-(4-methoxyphenoxy)benzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide, (R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-methylpiperazine-2-carboxamide, (R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-4-methylpiperazine-2-carboxamide, (R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-

- 22 -

piperazine-2-carboxamide, (R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide, 3(S)-N-hydroxyl-4-(4-(4-chlorophenoxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-thiazine-3-carboxamide, 2(R)-3,3-dimethyl-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide, 2(R)-3,3-dimethyl-N-hydroxy-1-(4-(4-fluorophenoxy) benzenesulfonyl)-piperazine-2-carboxamide, 2(R)-3,3-dimethyl-N-hydroxy-1-(4-(4-bromophenoxy)benzenesulfonyl)-piperazine-2-carboxamide, 2(R)-1-(4-(4-(chlorophenoxybenzenesulfonyl)-N-hydroxy-3,3,4-trimethylpiperazine-2-carboxamide, 2(R)-1-(4-(4-(fluorophenoxybenzenesulfonyl)-N-hydroxy-3,3,4-trimethylpiperazine-2-carboxamide, 3(S)-N-hydroxyl-4-(4-(4-chlorophenylsulfanyl)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-thiazine-3-carboxamide, 3(S)-N-hydroxyl-4-(4-(4-fluorophenylsulfanyl)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-thiazine-3-carboxamide, 2(R)-3,3-dimethyl-N-hydroxy-1-(4-(4-fluorophenylsulfanyl) benzenesulfonyl)-piperazine-2-carboxamide, 2(R)-3,3-dimethyl-N-hydroxy-1-(4-(4-chlorophenylsulfanyl)benzenesulfonyl)-piperazine-2-carboxamide, 2(R)-1-(4-(4-(4-fluorophenylsulfanyl)benzenesulfonyl)-N-hydroxy-3,3,4-trimethylpiperazine-2-carboxamide, 2(R)-1-(4-(4-(chlorophenylsulfanyl)benzenesulfonyl)-N-hydroxy-3,3,4-trimethylpiperazine-2-carboxamide, 2(R),3(S)-N-hydroxyl-4-(4-(pyrid-4-yl)oxy) benzenesulfonyl)-2-methyl-tetrahydro-2H-thiazine-3-carboxamide, 2(R),3(S)-N-hydroxyl-4-(4-(pyrid-4-yl)sulfanyl)benzenesulfonyl)-2-methyl-tetrahydro-2H-thiazine-3-carboxamide, and a compound of formula:

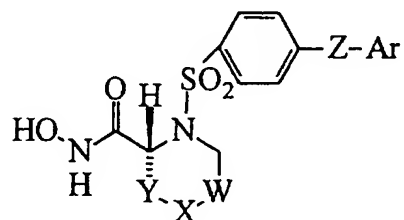


The inventive compounds may exist as single stereoisomers, racemates and/or mixtures of enantiomers and/or diastereomers. All such

- 23 -

single stereoisomers, racemates and mixtures thereof are intended to be within the scope of the present invention.

Preferably, the hydroxamate-bearing carbon, i.e., the carbon atom designated with "*" in formulas 1-a and 1-g, is in the "R" configuration when X is CH₂, C=O, O, N-R₃, or N⁺(O⁻)-R₄ and in the "S" configuration when X is S or S=O. It is understood by those skilled in the art that this difference in designating configuration is a consequence of the sequence rules of the Cahn-Ingold-Prelog system. When X is S=O, the sulfur atom is also preferably in the "R" configuration in relation to the preferred "S" configuration at the hydroxamate-bearing carbon atom. Thus a preferred compound is a compound of the formula:



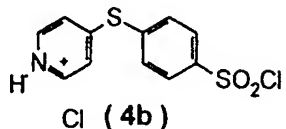
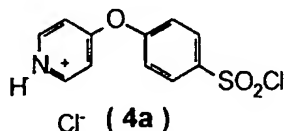
wherein X, W, Y, Z, and Ar are as defined above for formula 1-a. As generally understood by those skilled in the art, an optically pure compound having one chiral center (i.e., one asymmetric carbon atom) is one that consists essentially of one of the two possible enantiomers (i.e., is enantiomerically pure), and an optically pure compound having more than one chiral center is one that is both diastereomerically pure and enantiomerically pure.

Preferably, the compounds of the present invention are used in a form that is at least 90% optically pure, that is, a form that contains at least 90% of a single isomer (80% enantiomeric excess ("e.e.") or diastereomeric excess ("d.e.")), more preferably at least 95% (90% e.e. or d.e.), even more preferably at least 97.5% (95% e.e. or d.e.), and most preferably at least 99% (98% e.e. or d.e.).

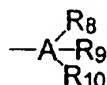
In the above described methods and intermediates, for conversions 1, 2, and 8-12 and for compounds 3, 4, 8, 9, and 10 preferably D is N. For conversions 2, 8, and 10 and for compound 4, preferably J is Cl.

- 24 -

Particularly preferred intermediates of formula 4 useful in conversions 2, 8, and 10 are salts of formulas 4a and 4b:

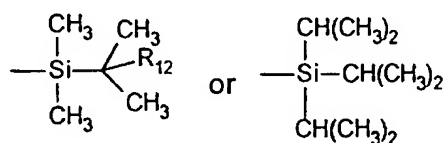


For conversions 5 and 6 and 8-13 and for compounds 7, 8, and 9, when Q is a group of formula:



and A is C, preferably R_8 is H,

an alkyl group, an O-alkyl group, an S-alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, $\text{C}\equiv\text{N}$, or $\text{C}(\text{O})\text{R}_{11}$, wherein R_{11} is an alkyl group, an aryl group, a cycloalkyl group, a heteroaryl group, or a heterocycloalkyl group, and R_9 and R_{10} are independently selected from H, an alkyl group and an aryl group. For these same conversions and compounds, when A is Si, preferably R_8 , R_9 and R_{10} are independently selected from an alkyl group, a cycloalkyl group, and an aryl group. More preferably, for these conversions and compounds Q is CH_3 , CH_2CH_3 , $\text{CH}(\text{CH}_3)_2$, $\text{C}(\text{CH}_3)_3$, $\text{CH}_2\text{-CH=CH}_2$, $\text{CH}_2\text{C}\equiv\text{N}$, or a group of the formula:

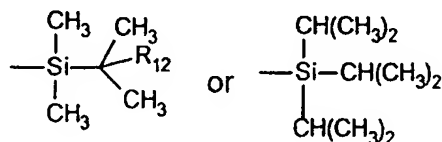


wherein R_{12} is CH_3 or $\text{CH}(\text{CH}_3)_2$.

For conversion 4 and for compound 6, preferred embodiments of the inventive methods and compounds are those such that when Q is an $\text{A}(\text{R}_8)(\text{R}_9)(\text{R}_{10})$ group as shown above and A is C, preferably R_8 is H, an alkyl group, an O-alkyl group, an S-alkyl group, a cycloalkyl group, a heterocycloalkyl group, an aryl group, a heteroaryl group, $\text{C}\equiv\text{N}$, or $\text{C}(\text{O})\text{R}_{11}$, wherein R_{11} is an alkyl group, an aryl group, a cycloalkyl group, a heteroaryl group, or a heterocycloalkyl group, and R_9 and R_{10} are independently selected from H, an alkyl group and an aryl group. For this same conversion and

- 25 -

compound, when A is Si, preferably R_8 , R_9 and R_{10} are independently selected from an alkyl group, a cycloalkyl group, and an aryl group. More preferably, for this conversion and compound, Q is CH_3 , CH_2CH_3 , $CH(CH_3)_2$, $C(CH_3)_3$, $CH_2-CH=CH_2$, $CH_2C\equiv N$, or a group of the formula:



wherein R_{12} is CH_3 or $CH(CH_3)_2$.

For conversions 3-13 and for intermediates 6, 7, 8, and 9, preferably R_1 and R_2 are each a methyl group.

Particularly preferred compounds of formula 8, useful in conversions 8 and 9, are those of formula 8a, where D is N, R_1 and R_2 are each a methyl group, and Z is O, and of formula 8b, where D is N, R_1 and R_2 are each a methyl group, and Z is S. For compounds 9 and 10, preferably D is N and R_1 and R_2 are each a methyl group.

The present invention is further directed to methods of inhibiting metalloproteinase activity, for example in mammalian tissue, by administering a compound of the formula 1, 1-a, 1-f or 1-g, or a pharmaceutically acceptable prodrug, salt or solvate thereof. The activity of the inventive compounds as inhibitors of metalloproteinase activity, such as the activity of MMPs (including stromelysins, collagenases, gelatinases and/or matrilysin) and/or $TNF-\alpha$ convertase, may be measured by any of the methods available to those skilled in the art, including *in vivo* and/or *in vitro* assays. Examples of suitable assays for activity measurements include those described in *Anal. Biochem.*, vol. 147, p. 437 (1985), *Anal. Biochem.*, vol. 180, p. 110 (1989), *FEBS*, vol. 96, p. 263 (1992) and European Patent Application No. 0 606 046.

Administration of the compounds of the formula 1, 1-a, 1-f or 1-g, or their pharmaceutically acceptable prodrugs, salts or solvates, may be performed according to any of the accepted modes of administration available to those skilled in the art. Illustrative examples of suitable modes of

- 26 -

administration include oral, nasal, parenteral, topical, transdermal and rectal. Preferably, the mode of administration is oral.

The inventive compounds of the formula 1, 1-a, 1-f or 1-g, or their pharmaceutically acceptable prodrugs, salts or solvates, may be administered as a pharmaceutical composition in any suitable pharmaceutical form recognizable to the skilled artisan. Suitable pharmaceutical forms include, but are not limited to, solid, semisolid, liquid or lyophilized formulations, such as tablets, powders, capsules, suppositories, suspensions and aerosols. Preferably, the pharmaceutical form is a tablet or capsule for oral administration. The pharmaceutical composition may also include suitable excipients, diluents, vehicles and carriers as well as other pharmaceutically active agents, depending upon the intended use.

Acceptable methods of preparing suitable pharmaceutical forms of the pharmaceutical compositions are known to those skilled in the art. For example, pharmaceutical preparations may be prepared following conventional techniques of the pharmaceutical chemist involving steps such as mixing, granulating and compressing when necessary for tablet forms, or mixing, filling, and dissolving the ingredients as appropriate, to give the desired products for oral, parenteral, topical, intravaginal, intranasal, intrabronchial, intraocular, intraaural and/or rectal administration. Illustrative examples of such methods include those described in *Remington's Pharmaceutical Sciences*, 18th edition (1990).

Solid or liquid pharmaceutically acceptable carriers, diluents, vehicles or excipients may be employed in the pharmaceutical compositions. Illustrative solid carriers include starch, lactose, calcium sulphate dihydrate, terra alba, sucrose, talc, gelatin, agar, pectin, acacia, magnesium stearate and stearic acid. Illustrative liquid carriers include syrup, peanut oil, olive oil, saline solution and water. The carrier or diluent may include a suitable prolonged-release material, such as glyceryl monostearate or glyceryl distearate, alone or with a wax. When a liquid carrier is used, the preparation may be in the form of a syrup, elixir, emulsion, soft gelatin capsule, sterile

- 27 -

injectable liquid (e.g. solution), or a nonaqueous or aqueous liquid suspension.

A dose of the pharmaceutical composition contains at least a therapeutically effective amount of the active compound (i.e., a compound of the formula 1, 1-a, 1-f or 1-g, or their pharmaceutically acceptable prodrugs, salts or solvates) and preferably is made up of one or more pharmaceutical dosage units. An exemplary dosage unit for a mammalian host contains an amount of from 0.1 milligram up to 500 milligrams of active compound per kilogram body weight of the host, preferably 0.1 to 200 milligrams, more preferably 50 milligrams or less, and even more preferably about 10 milligrams or less, per kilogram of the host weight. The selected dose may be administered to a mammal, for example, a human patient in need of treatment mediated by inhibition of metalloproteinase activity, by any known method of administering the dose including: topically, for example, as an ointment or cream; orally; rectally, for example, as a suppository; parenterally by injection; or continuously by intravaginal, intranasal, intrabronchial, intraaural or intraocular infusion.

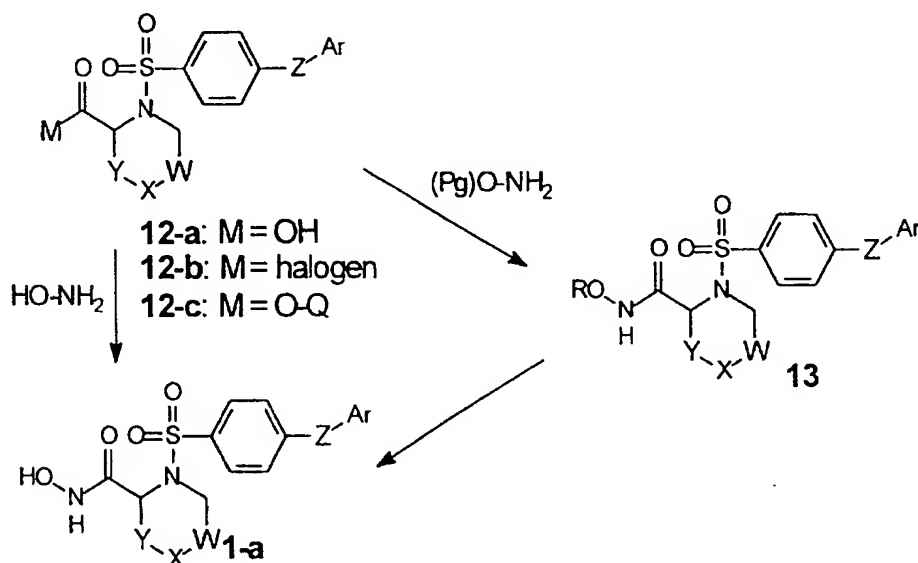
The amount of the inventive compounds, salts, solvates and/or prodrugs to be administered will vary based upon a number of factors, including the specific metalloproteinase to be inhibited, the degree of inhibition desired, the characteristics of the mammalian tissue in which inhibition is desired, the metabolic stability and activity of the particular inventive compound employed, and the mode of administration. One skilled in the art may readily determine a suitable dosage according to methods known to the art. Preferably, the amount of inventive compound of the formula 1, 1-a, 1-f or 1-g, or their pharmaceutically acceptable prodrugs, salts or solvates, administered is between 0.1 mg/kg body weight and 100 mg/kg body weight per day.

The inventive compounds, and the salts, solvates, and prodrugs thereof, may be prepared by employing the techniques available in the art using starting materials that are readily available. Exemplary methods of preparing the inventive compounds are described below. In the following

- 28 -

schemes, unless otherwise indicated, W, X, Y, Z, Ar, R₁ and R₂ are as previously defined herein.

The inventive compounds of the formula 1-a preferably can be prepared by reacting a compound of the formula 12-a (where M is a hydroxy group) with hydroxylamine in the presence of a suitable peptide coupling reagent. Illustrative examples of suitable coupling agents include 1,1'-carbonyl-diimidazole, N-(dimethylaminopropyl)-N'-ethyl carbodiimide ("EDC"), benzotriazol-1-yloxy-tris(dimethylamino)phosphonium hexafluorophosphate, or propanephosphonic anhydride in an inert polar solvent, such as dimethylformamide ("DMF").



Alternatively, a compound of the formula 12-b (where M is a halogen such as chlorine) can be reacted with hydroxylamine in a suitable solvent mixture such as tert-butanol-tetrahydrofuran ("THF")-dichloromethane, preferably at 0 to 25 °C, to give hydroxamates of the formula 1-a.

Compounds of the formula 12-b are preferably prepared in a form that is directly useful for further reaction without isolation. For example, such compounds can be prepared by allowing compounds of the formula 12-a to react with a suitable halogenating agent, such as thionyl chloride or oxalyl chloride, preferably in the presence of a catalytic amount of

- 29 -

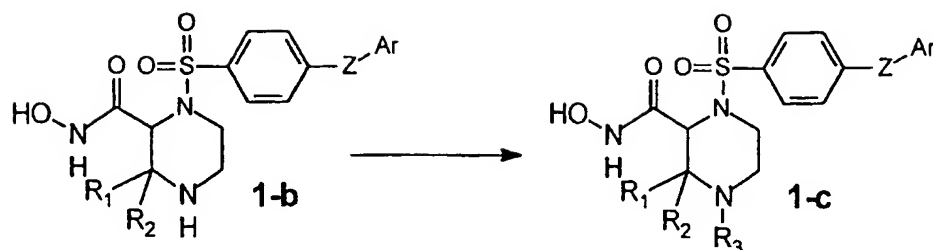
dimethylformamide, and preferably in a suitable solvent such as dichloromethane at a temperature from 0°C to room temperature.

Alternatively, the coupling reactions described above can be carried out with compounds of the formula **12-a** or **12-b** and oxygen-protected compounds of hydroxylamine (i.e., where Pg is a suitable protecting group known to those skilled in the art, such as benzyl, t-butyl, t-butyldimethylsilyl, or t-butyldiphenylsilyl, and/or described in T.W. Greene and P.G.M. Wuts, *Protective Groups in Organic Synthesis* (1991), the disclosure of which is incorporated herein by reference) to give compounds of formula **13**. Deprotection of compounds of the formula **13** provides compounds of formula **1-a**. Suitable methods of deprotecting compounds of the formula **13** are known in the art, for example, as described in T.W. Greene and P.G.M. Wuts, *Protective Groups in Organic Synthesis* (1991).

Compounds of the formula **12-a** can be prepared by alkaline hydrolysis of the corresponding ester **12-c** (where M = OQ, and Q is a suitable protecting group such as methyl, ethyl, allyl, benzyl or t-butyl) using a suitable aqueous base, such as lithium hydroxide, sodium hydroxide, or potassium hydroxide, preferably in a homogeneous aqueous-organic solvent mixture at a temperature from 0°C to 25°C. Alternatively, these compounds can also be prepared by acidic hydrolysis of the corresponding ester using a suitable aqueous acid, such as hydrochloric acid in aqueous dioxane, at a suitable temperature, preferably from 50°C to 100°C. Other methods recognizable by those skilled in the art as suitable for converting esters to acids can also be employed, such as hydrogenolysis of benzyl esters using hydrogen and palladium on carbon, acid-promoted cleavage of t-butyl esters under anhydrous conditions, and palladium-catalyzed cleavage of allyl esters.

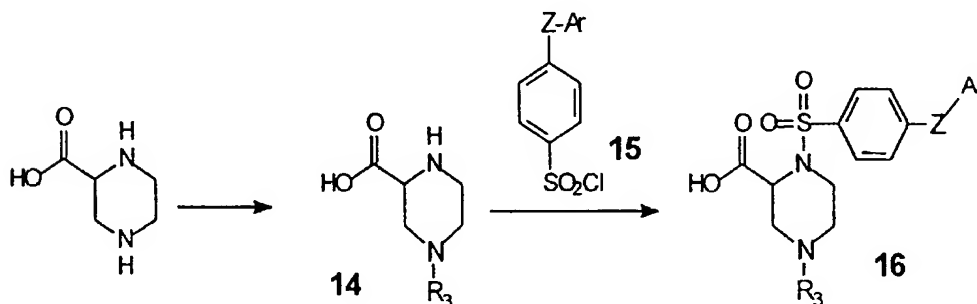
Compounds of the formula **1-c** (i.e., **1-a**, where W is CH₂ and Y is CR₁R₂ and X is N-R₃) in which R₃ is an alkyl group, can be prepared directly from compounds of the formula **1-b**, for example by treatment with a suitable alkylating agent, such as an alkyl halide or alkyl sulfonate ester, in a suitable solvent at an appropriate temperature, such as THF at a temperature from 0°C to 50°C.

- 30 -



Compounds of the formula 1-c where R_3 is an alkylsulfonyl group or an arylsulfonyl group can also be prepared directly from compounds of the formula 1-b. For example, treatment compounds of formula 1-b with 2 equivalents of trimethylchlorosilane in the presence of an excess of a tertiary base, such as 4-methylmorpholine, in an aprotic solvent, such as dichloromethane, at 25 °C, followed by treatment with an alkylsulfonyl chloride or an arylsulfonyl chloride at a temperature from 0 °C to 25 °C leads to, after a conventional aqueous work-up, compounds of formula 1-c where R_3 is alkylsulfonyl or arylsulfonyl. In a similar manner, compounds of formula 1-b can be reacted with the appropriate electrophilic carbonyl reagents to provide compounds of formula 1-c where R_3 is CO- R_3 , where R_3 is any suitable organic moiety.

Compounds of formula 16 (i.e., 12-a where W and Y are CH₂ and X is N- R_3) can be prepared according to the following scheme.



Preferably, commercially available racemic piperazine-2-carboxylic acid is allowed to react with a suitable electrophilic reagent R_3 -Lg, where Lg is any suitable leaving group, under conditions such that the reaction takes place predominantly at the N-4 position to give compounds of

the formula **14**. More preferably, the reaction takes place in aqueous-organic solvent, such as acetonitrile-water, at a temperature from -20°C to 25°C, and in the presence of excess base such as triethylamine.

For the preparation of enantiomerically pure compounds of the formula **16**, racemic piperazine-2-carboxylic acid can be first resolved according to known methods, such as those described in *Helv. Chim. Acta*, vol. 43, p. 888 (1960), and *Helv. Chim. Acta*, vol. 72, p. 1043 (1989), the disclosures of which are incorporated herein by reference.

Examples of suitable electrophilic reagents R_3 -Lg with suitable regioselectivity include BOC-ON, di-*t*-butyl dicarbonate, N-(benzyloxy-carboxy)succinimide, and acetic anhydride. The intermediate of the formula **14** is then preferably further reacted, without isolation, under the same conditions with a sulfonyl chloride of the formula **15** to give compounds of the formula **16**.

Alternatively, the intermediate of the formula **14** can be isolated and then allowed to react with trimethylsilyl chloride and a suitable tertiary amine base, such as triethylamine or 4-methylmorpholine. Without isolation, the resulting material is then reacted with a sulfonyl chloride **15** in a suitable solvent such as dichloromethane at 25 °C to provide, after conventional acid workup, a compound of the formula **16**.

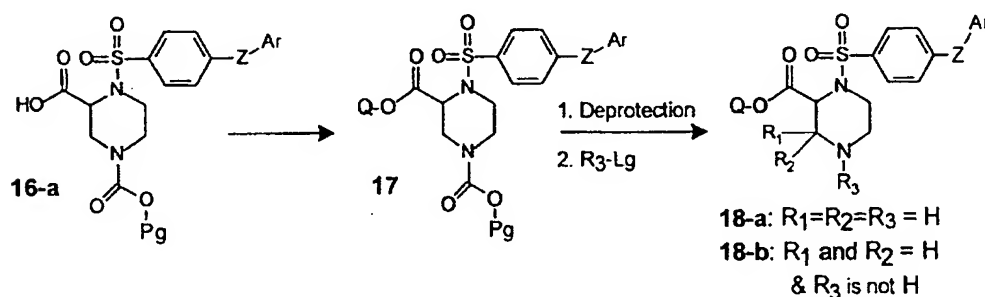
The intermediate of the formula **14** can also be prepared by treating the copper (II) complex of piperazine-2-carboxylate, prepared according to the method described in U.S. Patent No. 4,032,639, the disclosure of which is herein incorporated by reference, with R_3 -Lg, followed by decomplexation by acidification and ion-exchange chromatography using DOWEX 50 resin. With this procedure, a broad range of electrophilic reagents R_3 -Lg can be employed.

Compounds of formula **15** can be preferably prepared by treatment of the corresponding aryl/heteroaryl phenyl ether or aryl/heteroaryl phenyl thioether, which are commercially available or can be prepared by methods known to those skilled in the art, with an excess of chlorosulfonic acid in dichloromethane solution at a temperature from 0°C to 25°C.

- 32 -

Alternatively, the aryl phenyl ether can be treated with between 0.9 and 1.2 molar equivalents of chlorosulfonic acid at -20°C to 25°C . The resulting sulfonic acid, with or without isolation, can be subsequently converted to the sulfonyl chloride **15** with an excess of a chlorinating reagent, such as oxalyl chloride or thionyl chloride, in the presence of a catalytic amount of dimethylformamide ("DMF") in a suitable solvent, such as dichloromethane, 1,2-dichloroethane, or acetonitrile, at 25°C to 80°C .

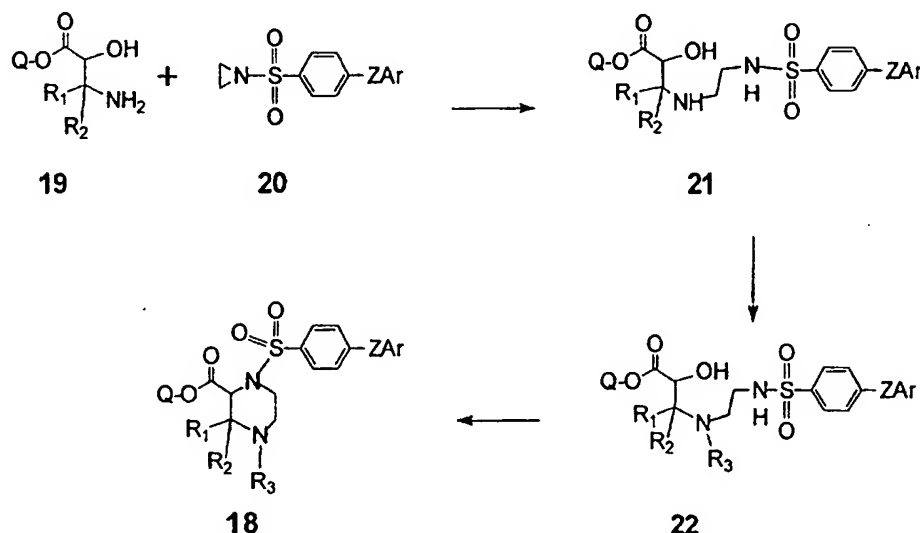
Alternatively, compounds of the formula **16-a**, where Pg is a suitable protecting group as described above, are first converted to the corresponding methyl esters **17** by conventional methods, such as treatment with trimethylsilyl diazomethane in a suitable solvent such as methanol-dichloromethane at room temperature as shown in the following scheme.



Suitable protecting groups, Pg, for this type of reaction are recognizable to those skilled in the art and include, but are not limited to, t-butyl groups and benzyl groups. Removal of the protecting group by known methods provides compounds of formula **18-a** where R_3 is hydrogen, which can be further reacted with reagents having the formula $R_3\text{-Lg}$, wherein Lg is any suitable leaving group, to give compounds of the formula **18-b** where R_3 is not hydrogen. Illustrative examples of suitable $R_3\text{-Lg}$ reagents include methanesulfonyl chloride, methyl iodide, methyl isocyanate, ethyl bromoacetate, dimethylcarbamoyl chloride, and methoxyacetic anhydride.

- 33 -

Compounds of formula **18** (i.e., **12-c** where W is CH₂, Y is CR₁R₂, and X is NR₃) can be prepared as illustrated in the scheme below.



β -Amino- α -hydroxy esters of formula **19** and aziridines of formula **20** are allowed to react in inert solvent such as dichloroethane or preferably dioxane at elevated temperature, 60 to 100 °C, to give adducts **21**. Derivatization of the amine function of **21** to provide compounds of formula **22** can be effected by conventional methods known to those skilled in the art. Cyclization of compounds of formula **22** under Mitsunobu-type conditions (see *J. Org. Chem.* **1991**, *56*, 3900-3905, the disclosure of which is incorporated herein by reference) provides the piperazines **18**.

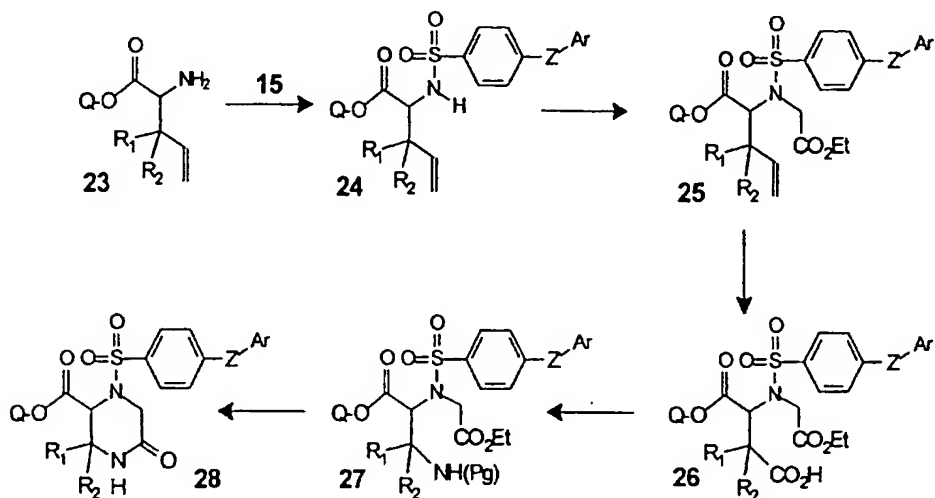
Compounds of formula **19** where R₁ is H and R₂ is alkyl can be prepared according to literature methods known to those skilled in the art. Where R₁ and R₂ are both methyl, the amino alcohols **19** are available from a nitronate alkylation as described in *Bull. Chem. Soc. Jpn.* **1976**, *49*, 3181-3184, the disclosure of which is incorporated herein by reference.

The aziridines **20** can be prepared by treatment of sulfonyl chlorides of formula **15** with excess ethanolamine in THF at -20 °C to 25 °C, followed by cyclization of the resulting β -hydroxyethyl sulfonamides with

- 34 -

DEAD and triphenylphosphine in THF. Compounds of formula 15 can be prepared as described above.

Compounds of formula 28 (i.e., 12-c where X is NH, W is C=O, and Y is CR₁R₂) can be prepared according to the following scheme.

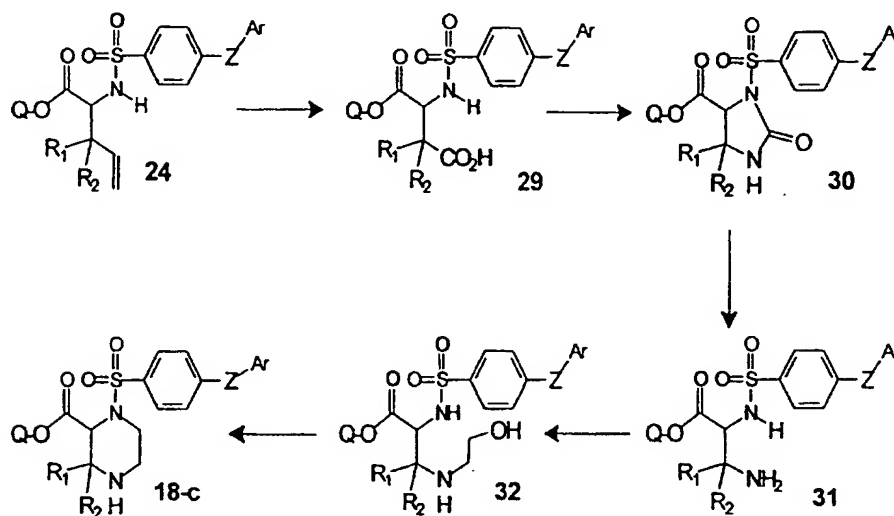


Treatment of compounds of formula 23 (prepared as described in *Angew. Chem. Int. Ed. Engl.* 1994, 33, 998-999, the disclosure of which is incorporated herein by reference) with sulfonyl chlorides of formula 15, as described above, give compounds of formula 24. Alkylation of compounds of formula 24 with ethyl bromoacetate proceeds in the presence of a suitable base, such as potassium carbonate, in a suitable solvent, such as DMF, at 25 °C to 80 °C for a period of 1 to 48 hours to provide compounds of formula 25. Oxidation of alkenes 25 to compounds of formula 26 proceeds under suitable oxidizing conditions, such as excess sodium periodate in the presence of catalytic ruthenium trichloride in acetonitrile:carbon tetrachloride:water (2:2:3) solvent at 25 °C for 1 to 18 hours. Treatment of compounds of formula 26 with diphenylphosphoryl azide ("DPPA") in the presence of a suitable base, such as triethylamine, in an inert solvent, such as benzene, at 70-100 °C for 1-12 hours gives an intermediate isocyanate, which upon addition of a suitable alcohol, such as benzyl alcohol, provides compounds of formula 27, where Pg is a corresponding protecting such as benzyloxycarbonyl protecting

- 35 -

group. Removal of the protecting group from compounds of formula 27 under conventional conditions leads to spontaneous lactamization to provide compounds of formula 28.

An alternative sequence making use of the intermediates of formula 24 is shown below.

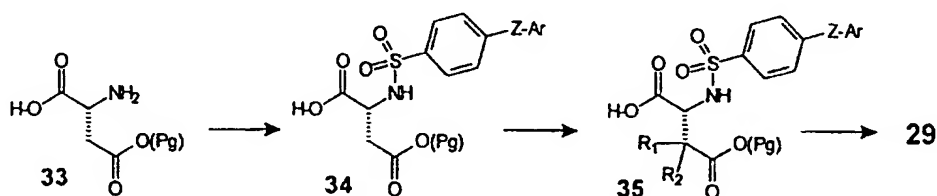


Oxidation of compounds of formula 24 under the conditions described in the preceding paragraph for the oxidation of compounds of formula 25 gives compounds of formula 29. Curtius rearrangement of acids 29, as described for the conversion of 26 to 27 above except in the absence of added alcohol, leads to formation of compounds of formula 30. Mild basic hydrolysis of compounds of formula 30 with, for example, 1 molar equivalent of lithium hydroxide in THF-water at 0 °C for 0.5 to 18 hours leads to compounds of formula 31. Reaction of amines of formula 31 with excess ethylene oxide in alcoholic solvent at 25 °C to 75 °C for 1 to 18 hours provides compounds of formula 32, which upon treatment with DEAD and triphenylphosphine in THF at 25 °C yields compounds of formula 18-c. It will be appreciated by those skilled in the art that utilization of enantiomerically-enriched compounds of formula 24, which are accessible utilizing the methods reported in the

- 36 -

literature and known to those skilled in the art, will yield enantiomerically-enriched compounds of formula **28** and **18-c**.

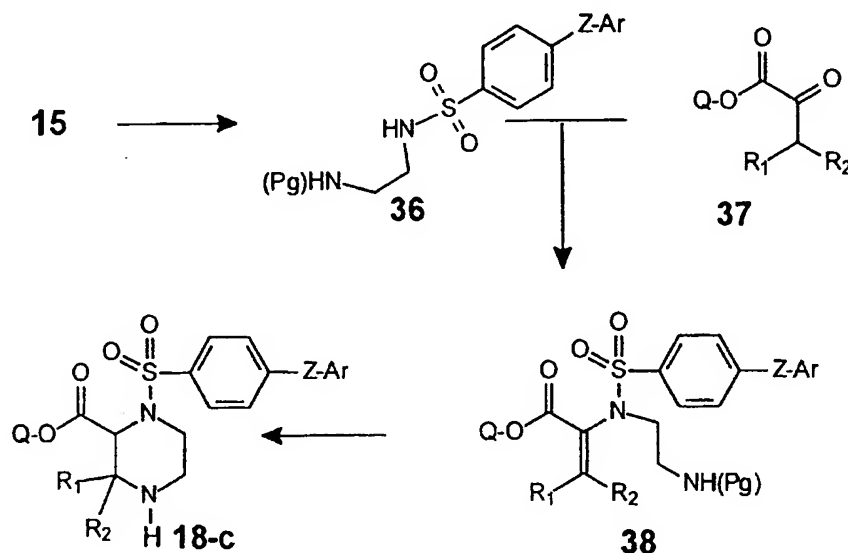
Alternatively, the intermediate compounds of formula **29** can be prepared in enantiomerically-enriched form according to the following scheme.



Treatment of compounds of formula **33**, which are readily derived from D-aspartic acid by methods known to those skilled in the art, with trimethylsilyl chloride and triethylamine in dichloromethane at 25°C for approximately 1 hour provides the trimethylsilyl esters, which, without isolation, are further reacted with aryl sulfonyl chlorides of the formula **15** in the presence of additional base to provide, after conventional work-up, the corresponding sulfonamides of the formula **34**. Treatment of a sulfonamide **34** with approximately 3 molar equivalents of a strong base, such as lithium diisopropylamide ("LDA"), at a temperature between -78 °C and 0 °C in an inert solvent such as THF, followed with 1 equivalent of an appropriate lower alkyl halide of the formula R₁-X, preferably at a temperature between 0°C and -78°C, gives a mono-alkylated product of formula **35** where R₂ is H. Without isolation, the reaction mixture is treated with an additional equivalent of base, and then allowed to react with a second alkyl halide of the formula R₂-X, where R₁ and R₂ are preferably the same, but can be different, to give, after acidic work-up, a sulfonamide of the formula **35**. Following esterification of the carboxylic acid function of **35**, the protecting group Pg is removed to provide the acid **29**.

- 37 -

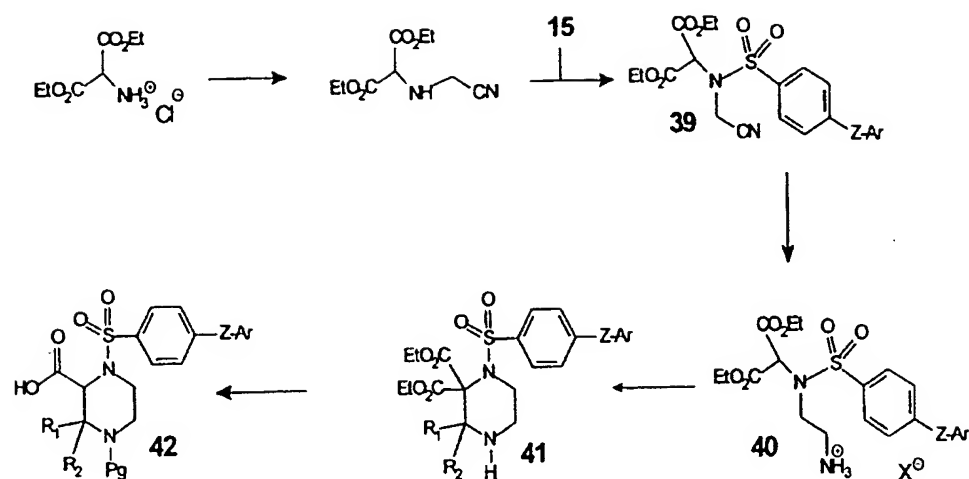
Alternatively, compounds of the formula **18-c** can be prepared according to the following scheme.



Arylsulfonyl chlorides of formula **15** can be converted to sulfonamides of formula **36** by reaction with monoprotected derivatives of ethylenediamine. Condensation of a sulfonamide **36** with an α -keto ester of the formula **37** in the presence of an acid catalyst, such as *p*-toluenesulfonic acid, provides a compound of the formula **38**. Conversion of a compound of the formula **38** to the corresponding compound of the formula **18-c** is effected by cyclization in the presence of catalytic base, such as potassium carbonate, in a suitable solvent, such as DMF, followed by removal of the protecting group Pg.

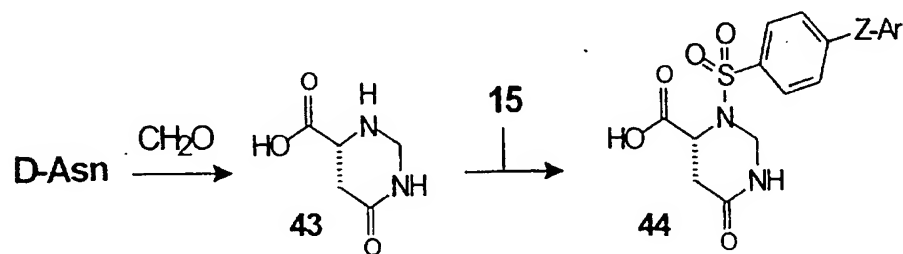
Additionally, compounds of the formula **42** (i.e., **12-a** where X is N-R_3 , W is CH_2 , and Y is CR_1R_2) can be prepared according to the following scheme.

- 38 -



Treatment of diethyl aminomalonate, which is commercially available, with chloroacetonitrile or bromoacetonitrile in the presence of diisopropylethyl amine in ethyl alcohol provides diethyl (cyanomethyl)aminomalonate, which is further reacted with an arylsulfonyl chloride of the formula 15 to give a compound of the formula 39. Nitriles of the formula 39 are reduced to corresponding amine salts of the formula 40 by hydrogenation over a suitable metal catalyst, such as palladium or platinum, in the presence of acid in alcohol solution. Reaction of a amine salt of the formula 40 with an excess of a ketone $\text{R}_1-\text{CO}-\text{R}_2$ gives a piperazine derivative of the formula 41. After protection of the amine function by conventional methods known to those skilled in the art, basic hydrolysis of the ethyl esters followed by decarboxylation under acid conditions provides a compound of the formula 42.

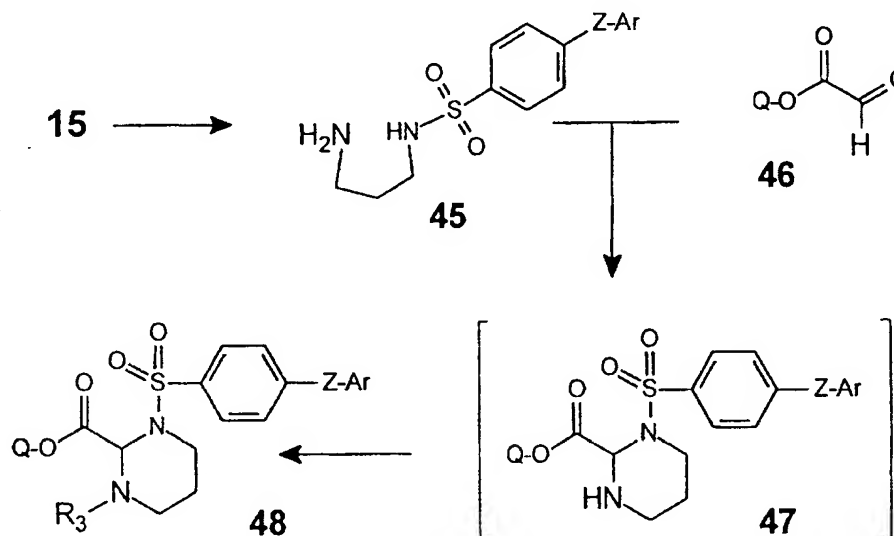
Compounds of the formula 44 (i.e., 12-a where where W is N-H, X is C=O, and Y is CH) can be prepared according to the following scheme.



- 39 -

Preferably, a warm aqueous solution of D-asparagine, which is commercially available, is treated with formalin to provide, after cooling to 0 °C, 6(R)-carboxy-tetrahydropyrimidin-4-one (**43**). Treatment of 6(R)-carboxy-tetrahydropyrimidin-4-one with trimethylsilylchloride in a suitable base, such as N-methylmorpholine or diisopropylethylamine, in a polar aprotic solvent, such as DMF, generates the corresponding trimethylsilyl ester. This ester can be treated, without isolation, with a sulfonyl chloride **15** in the presence of additional base for several hours at 25 °C to provide, after aqueous work-up, a compound of the formula **44**. Alternatively, the compound of the formula **44** can be prepared directly by treating a solution of 6(R)-carboxy-tetrahydropyrimidin-4-one and a base, such as N-methyl-morpholine, in a suitable aqueous:organic mixed solvent, such as water:dioxane, with a sulfonyl chloride of the formula **15** at 25 °C for several hours followed by aqueous acid work-up.

Compounds of formula **48** (i.e., compounds of formula **12-c** where W and X are CH₂ and Y is N-R₃) can be prepared according to the following scheme.



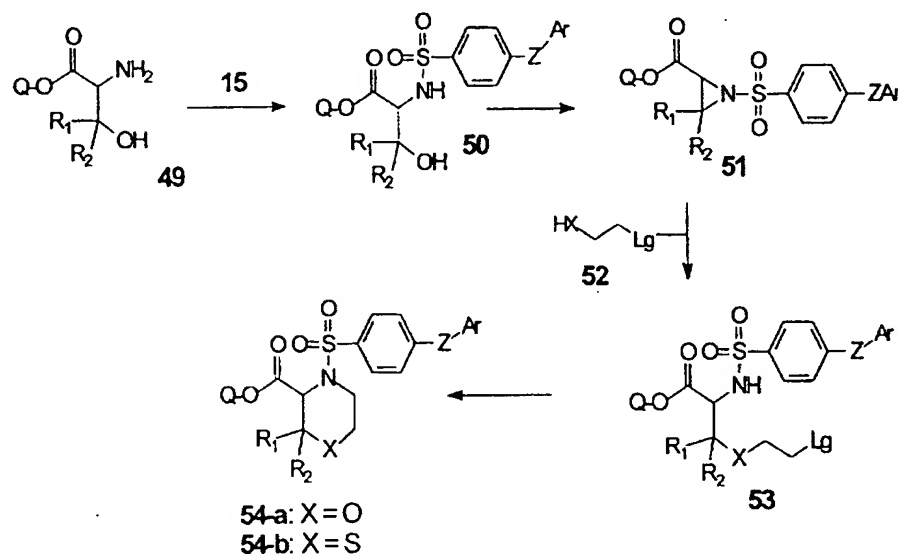
Slow addition of compounds of formula **15**, as a solution in a inert solvent such as dichloromethane, to four molar equivalents of 1,3-diaminopropane in the same solvent at -20 °C to 0 °C provides the

- 40 -

compounds of formula **45**, which are readily isolated by a acid-base extraction sequence to remove small amounts of the bis-sulfonamide byproduct.

Treatment of amines **45** with glyoxalate esters of formula **46**, which are commercially-available or well-known in the literature, provides intermediates of formula **47**, which can exist partially or substantially as the corresponding open-form imine tautomers. Reaction of compounds **47** with an appropriate electrophilic reagent $R_3\text{-Lg}$ then provides compounds of formula **48**.

A method for preparing compounds of formula **54**, where X is O or S, is shown in the scheme below.



The starting β -hydroxy α -amino esters **49** are either commercially available, for example serine, threonine, and *allo*-threonine esters, or can be prepared by methods described in the literature (see, for example, *J. Org. Chem.*, **1996**, *61*, 2582-2583, the disclosure of which is incorporated herein by reference). Compounds of formula **49** are treated with an sulfonyl chloride having the formula **15** in the presence of a suitable tertiary amine base, such as N-methylmorpholine, in an aprotic solvent, such as DMF-dichloromethane,

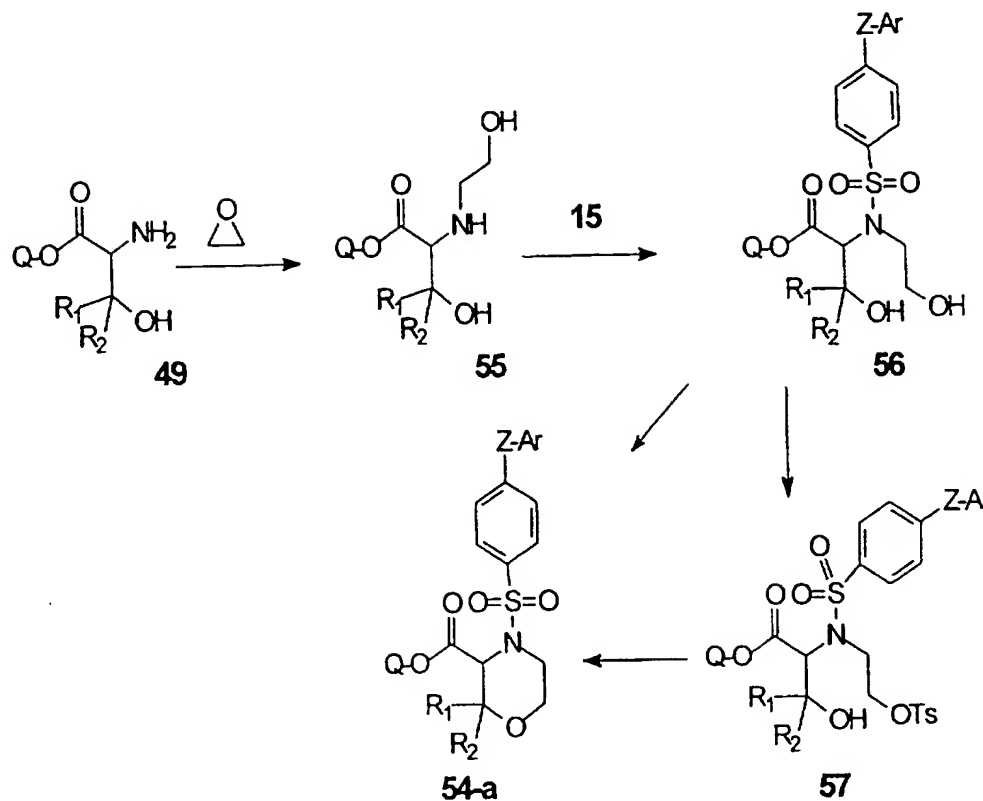
- 41 -

at 0°C to 25°C to provide the β -hydroxy α -sulfonylamino esters having the formula **50**.

Treatment of compounds of the formula **50** with suitable dehydrating reagents, for instance triphenylphosphine and DEAD in THF solution at 25 °C, provide the sulfonylaziridines of formula **51**. Treatment of aziridines of formula **51** with a thiol (X = S) or alcohol (X = O) of formula **52**, where Lg is any suitable leaving group (or a precursor, such as hydroxyl, to such a leaving group) in the presence of a Lewis acid, such as boron trifluoride etherate, at 0°C to 25°C, either without additional solvent or in a suitable inert solvent such as dichloromethane, yields compounds of formula **53**. Subsequent treatment of the compounds having the formula **53** with a base such as potassium carbonate in an aprotic solvent such as DMF then provides compounds of formula **54**. In the case where Lg is hydroxyl, cyclization of **53** to give **54** is effected with triphenylphosphine and DEAD in THF solution at 25°C.

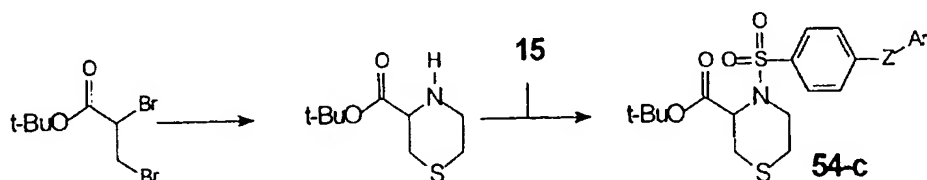
Alternatively, compounds of formula **54-a** can be prepared from amino esters **49** by the sequence shown below.

- 42 -



Hydroxyethylation of amino esters **49** can be effected with ethylene oxide in alcoholic solvent at 25 °C to 70 °C to provide compounds of formula **55**, which can be converted to compounds of formula **56** by treatment with sulfonyl chlorides **15**. Diol **56** can be cyclized with the Mitsunobu protocol (see Holladay, M. W.; Nadzan, A. M. *J. Org. Chem.* **1991**, *56*, 3900-3905), or in traditional Williamson-style via the tosylate **57** and base to give compound of formula **54-a**.

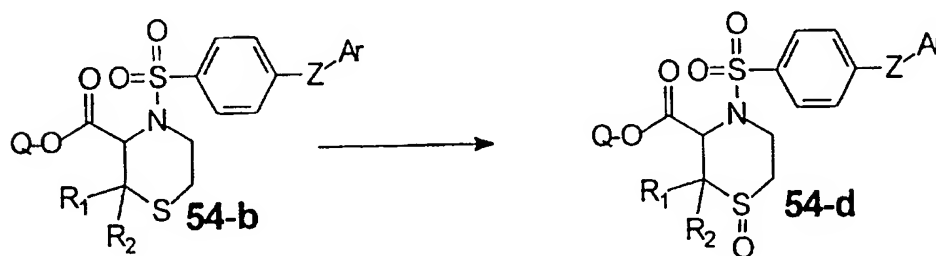
Alternatively, compounds of the formula **54-c** (i.e., **54-b** where Q is tert-butyl, X is S and R₁ and R₂ are both hydrogen) can be prepared according to the following scheme.



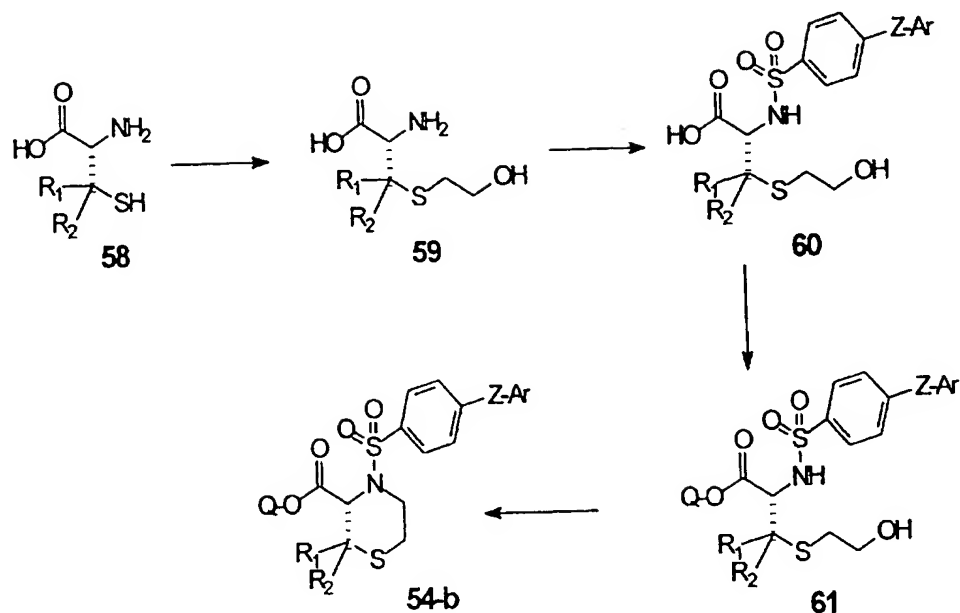
Preferably, t-butyl 2,3-dibromopropionate (prepared according to the method described in *J. Perkin Trans I*, p. 1321 (1973), the disclosure of which is incorporated herein by reference) is treated with 2-mercaptoethylamine and triethylamine in a suitable solvent, such as a mixture of chloroform and benzene, to provide t-butyl tetrahydro-1,4-thiazine-3-carboxylate, which upon reaction with a compound of the formula **15** under suitable conditions, such as in the presence of triethylamine in dichloromethane solution at 25 °C, provides compounds of the formula **54-c**.

As shown in the scheme below, oxidation of tetrahydrothiazines of formula **54-b** to the corresponding sulfoxides of formula **54-d** can be carried out under suitable oxidizing conditions, such as m-chloroperbenzoic acid in dichloromethane at -78 °C to 0 °C or sodium perborate in acetic acid at 25 °C to 50 °C. It is to be understood that such oxidations can also be carried out at other intermediate stages in the synthesis of compounds of formula **1-a** where X is S=O, and also to directly convert compounds of formula **1-a** where X is S to compounds of formula **1-a** where X is S=O.

Compounds of the formula **54-b** can be prepared according to



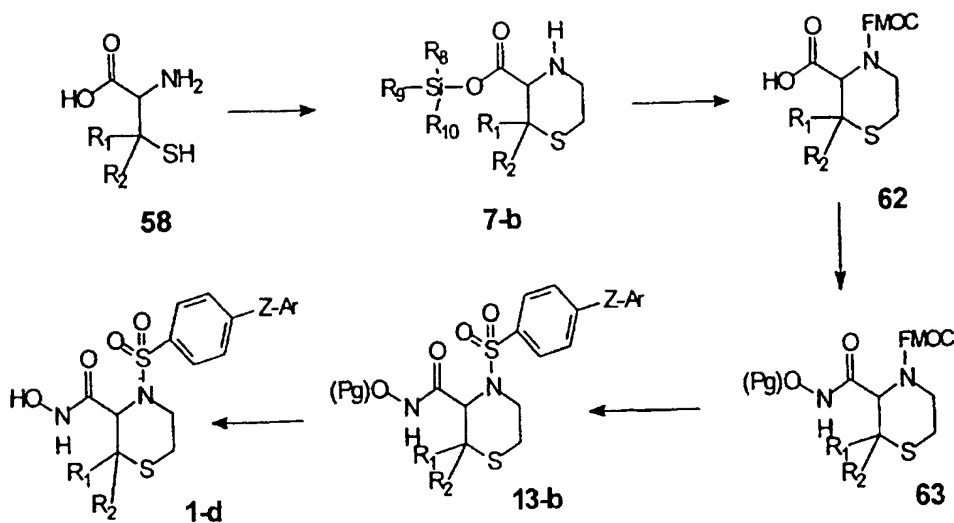
the following scheme.



First, β -mercapto- α -amino acids of formula **58**, such as D-penicillamine or D-cysteine, both of which are commercially available, are treated with 2-bromoethanol in the presence of a base, such as sodium hydroxide, to provide 2-hydroxyethyl sulfides of formula **59**. Intermediates of formula **59** are then reacted directly with compounds of the formula **15** in the presence of a suitable base, such as sodium carbonate, in an appropriate solvent system, such as DMF/water to provide the N-sulfonyl derivatives **60**. The acid function of compounds of formula **60** is then protected as a suitable ester group Q, for example, the t-butyl ester which is prepared by reaction of **60** with t-butyl bromide in the presence of a suitable base, such as potassium carbonate, and a suitable catalyst, such as benzyltriethylammonium chloride ("BTEAC") in dimethylacetamide at a temperature between 50°C and 60°C. Cyclization of the compound of the formula **61** can be effected using triphenylphosphine and DEAD in a suitable solvent, such as THF, to yield a compound of the formula **54-b**.

More preferably, compounds of the formula **1-d** (e.g., **1-a** where W is CH₂, X is S, and Y is CR₁R₂) can be prepared according to the following scheme.

- 45 -



Treatment of compounds of formula 58 with a trialkylsilyl chloride, such as trimethylsilyl chloride, in the presence of a tertiary amine base, such as diisopropylethylamine, in an aprotic solvent, such as DMF, provides the corresponding trialkylsilyl ester, which upon reaction with 1,2-dichloroethane or 1,2-dibromoethane in the presence of DBU at 25 °C gives the intermediate tetrahydrothiazine of the formula 7-b. Without isolation, this intermediate is further reacted with 9-fluorenylmethyl chloroformate ("Fmoc-Cl") in the presence of additional base, such as N-methyl morpholine, to provide, after aqueous acidic workup, the free carboxylic acid of the formula 62. This acid can then be coupled to an O-protected hydroxylamine, for example where Pg is t-butyldiphenylsilyl, with conventional peptide coupling reagents, such as EDC, to give the protected hydroxamate of the formula 63. Removal of the Fmoc protecting group with conventional methods, such as piperidine in DMF, followed by reaction with a sulfonyl chloride of the formula 15 in the presence of base, such as N-methyl morpholine, in a suitable solvent, such as dichloromethane, provides compounds of the formula 13-b. Removal of the protecting group Pg affords compounds of the formula 1-d.

Particularly preferred compounds of this invention are compounds of formula 10. The preparation of compounds of formula 64-b described above can be applied to the synthesis of compounds of formula 10.

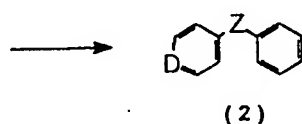
More preferably, however, compounds of the formula **10** are prepared according to the process described below.

Summary of the Process

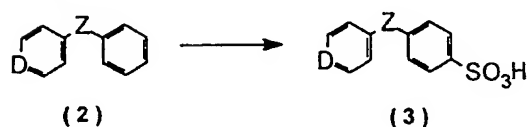
One aspect of the present invention is a process for the synthesis of certain matrix metalloprotease inhibitors, represented by the formula **10**.

The reaction scheme can be summarized as involving the following steps:

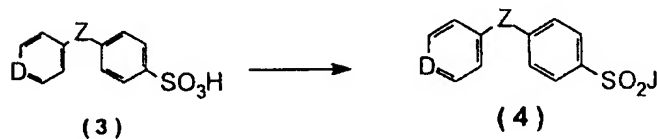
Step 1



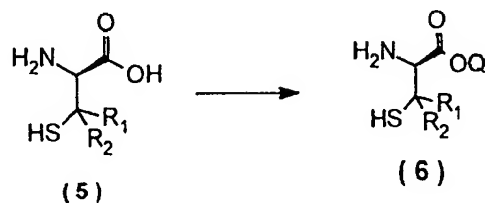
Step 2



Step 3

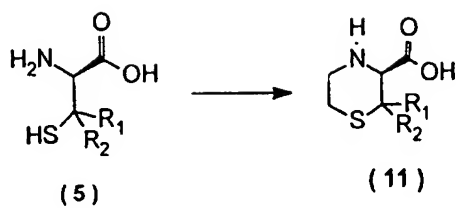


Step 4

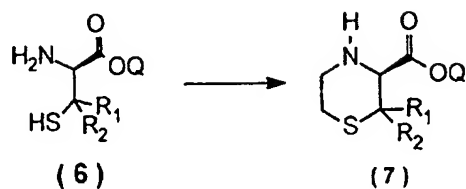


- 47 -

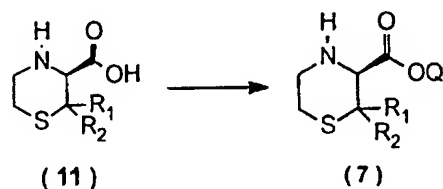
or Step 4A



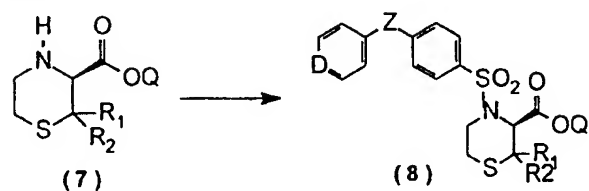
Step 5



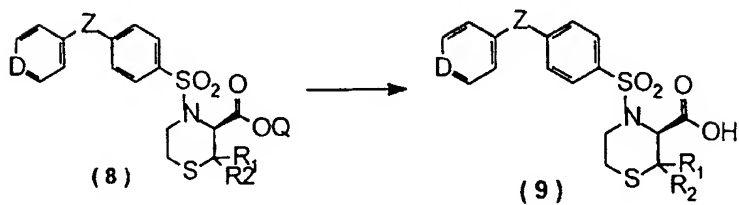
or Step 5A

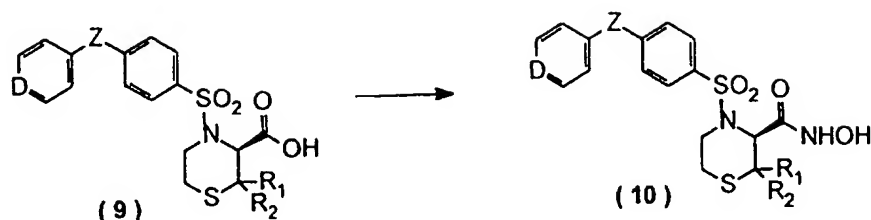


Step 6



Step 7



Step 8

The process comprises combining a suitably activated two-carbon piece with the amino acid 5 to form a tetrahydro-2H-1,4-thiazine derivative 11 or with a suitable ester 6 to form a tetrahydro-2H-1,4-thiazine derivative 7. A compound of formula 7 is treated with an activated sulfonic acid derivative 4 to give the corresponding sulfonamide 8. The ester functionality Q in compound 8 is deprotected to give compound 9, which is then activated by formation of an acid chloride or other suitable activating group. The activating group is displaced by hydroxylamine or a suitable salt or derivative of hydroxylamine to give the hydroxamic acid 10. The activated diarylether sulfonic acid derivative 4 can be prepared from the diaryl ether 2 by chlorosulfonation directly to the sulfonyl chloride or by a stepwise process of sulfonation to the sulfonic acid 3, followed by conversion to the sulfonyl chloride or other suitably activated sulfonic acid derivative.

Detailed Description of the Process

A number of diarylethers 2 are commercially available. In cases where the diarylether is not commercially available, the first step of the process involves preparing the diarylether 2. In the case where D is nitrogen, compounds 2 can be made by combining either 4-chloropyridine hydrochloride or 1-(4-pyridyl)pyridinium chloride hydrochloride with phenol or thiophenol at or above 100°C either neat or in water, toluene, xylenes, or other suitable solvent.

In Step 2 of the process, the diaryl ether is treated with chlorosulfonic acid, sulfuric acid, sulfur trioxide, or other suitable sulfonating agent to give the sulfonic acid 3, which is used directly or isolated by water

quench followed by solvent removal or extraction into a suitable water immiscible organic solvent. In some cases, a quaternary ammonium salt such as tetrabutylammonium bromide can be used to increase the solubility of the sulfonic acid **3** in organic solvents.

Step 3 of the process involves adding thionyl chloride, oxalyl chloride, chlorosulfonic acid, phosphorus pentachloride, or another suitable chlorinating reagent to the sulfonic acid **3** in acetonitrile, dichloromethane, 1,2-dichloroethane, or another suitable organic solvent. The resulting sulfonyl chloride **4** can be isolated by solvent removal or water quench followed by filtration or extraction. Alternatively, the sulfonic acid **3** can be converted to the sulfonyl fluoride with fluorosulfonic acid or sulfonyl bromide with thionyl bromide. If desired, the sulfonyl chloride, sulfonyl fluoride, and sulfonyl bromide compounds can be converted to the more stable triazolidine or benzotriazolidine derivatives by treatment with 1,2,4-triazole or benzotriazole respectively.

In Step 4, compound **5** is converted to a suitable silyl or carbon ester. In the cases where a silyl ester is utilized, trimethylsilyl chloride, tert-butyldimethylsilyl chloride, dimethylhexylsilyl chloride, triisopropylsilyl chloride, or another suitable silylating reagent is added to a mixture of compound **5** and 1,8-diazabicyclo[5.4.0]undec-7-ene, triethylamine, diisopropylethylamine, 4-methylmorpholine, pyridine, or other suitable tertiary amine base in N,N-dimethylformamide, acetonitrile, dichloroethane, or other suitable aprotic solvent. The resulting mixture of the silyl ester **6** can be used directly in Step 5, or the silyl ester can be isolated by aqueous work-up, extraction, and solvent removal.

In the cases where a carbon ester is utilized, a mixture of compound **5** and sulfuric acid, hydrogen chloride, p-toluenesulfonic acid, or another suitable organic or mineral acid in methanol, ethanol, isopropanol, 1-butanol, tert-butanol, allyl alcohol, or other suitable alcohol solvent is heated at reflux for 4 to 60 hours. The resulting ester is isolated as either the free base or amine salt by solvent removal and/or aqueous work-up, followed by extraction with an appropriate solvent and finally solvent removal or salt

- 50 -

formation by addition of an appropriate acid. Alternatively, the tert-butyl ester can be prepared by maintaining a mixture of compound 5 in liquid isobutylene, a suitable organic solvent such as 1,4-dioxane, and a suitable mineral acid or organic acid such as sulfuric acid, hydrogen chloride, or p-toluenesulfonic acid at reflux for 4 to 60 hours.

In Step 4A, compound 5 is mixed with 1,8-diazabicyclo[5.4.0]undec-7-ene, sodium hydroxide, potassium hydroxide, or other suitable organic or inorganic base, and 1,2-dichloroethane, 1,2-dibromoethane, or other suitable activated two carbon moiety in 1,2-dichloroethane, N,N-dimethylformamide, methanol, ethyl acetate, tetrahydrofuran, acetonitrile, water or other appropriate solvent. The resulting tetrahydro-2H-1,4-thiazine derivative 11 is isolated by precipitation, followed by filtration or by solvent removal. Alternatively, the carboxylic acid functionality of compound 5 can be protected in-situ by addition of trimethylsilyl chloride and 1,8-diazabicyclo[5.4.0]undec-7-ene. The resulting silyl ester is treated with 1,2-dichloroethane, 1,2-dibromoethane, or another suitable activated two carbon moiety and 1,8-diazabicyclo[5.4.0]undec-7-ene or another suitable tertiary amine base in 1,2-dichloroethane, N,N-dimethylformamide, or other suitable aprotic solvent. The silyl ester is deprotected in-situ by addition of methanol, 2-propanol, or another alcoholic solvent and the resulting tetrahydro-2H-1,4-thiazine derivative 11 is isolated by precipitation and filtration.

In Step 5, the ester 6 is treated with 1,8-diazabicyclo[5.4.0]undec-7-ene, sodium hydroxide, potassium hydroxide, or other suitable organic or inorganic base, and 1,2-dichloroethane, 1,2-dibromoethane, or other suitable activated two carbon moiety in 1,2-dichloroethane, N,N-dimethylformamide, methanol, ethyl acetate, tetrahydrofuran, acetonitrile, or other appropriate solvent. The resulting tetrahydro-2H-1,4-thiazine derivative 7 is isolated by precipitation or aqueous work-up followed by extraction with an organic solvent and solvent removal.

In Step 5A, compound 11 is converted to a suitable silyl or carbon ester. In the cases where a silyl ester is utilized, trimethylsilyl chloride,

- 51 -

tert-butyldimethylsilyl chloride, dimethylhexylsilyl chloride, triisopropylsilyl chloride, or another suitable silylating reagent is added to a mixture of compound 11 and 1,8-diazabicyclo[5.4.0]undec-7-ene, triethylamine, diisopropylethylamine, 4-methylmorpholine, pyridine, or other suitable tertiary amine base in N,N-dimethylformamide, acetonitrile, dichloroethane, or other suitable aprotic solvent. The resulting mixture of the silyl ester 7 can be used directly in Step 6, or the silyl ester can be isolated by aqueous work-up, extraction, and solvent removal.

In the cases where a carbon ester is utilized, a mixture of compound 11 and sulfuric acid, hydrogen chloride, p-toluenesulfonic acid, or another suitable organic or mineral acid in methanol, ethanol, isopropanol, 1-butanol, tert-butanol, allyl alcohol, or other suitable alcohol solvent is heated at reflux. The resulting ester is isolated as either the free base or amine salt by solvent removal and/or aqueous work-up, followed by extraction with an appropriate solvent, and finally solvent removal or salt formation by addition of an appropriate acid. Alternatively, the tert-butyl ester can be prepared by maintaining a mixture of compound 11 in 1,4-dioxane or other suitable solvent, liquid isobutylene, and sulfuric acid, hydrogen chloride, p-toluenesulfonic acid, or another suitable mineral acid or organic acid at reflux.

Alternatively, the tetrahydro-2H-1,4-thiazine derivative 11 can be left unprotected and used directly in Step 6. In this case, Step 5A is simply omitted.

In Step 6, the tetrahydro-2H-1,4-thiazine derivative 7 or 11 and the activated diarylether sulfonic acid derivative 4 are combined in dichloromethane, 1,2-dichloroethane, acetonitrile, N,N-dimethylformamide, ethyl acetate, toluene, tert-butyl methyl ether, or another suitable solvent in the presence of 4-methylmorpholine, pyridine, triethylamine, diisopropylethylamine, potassium carbonate, or another suitable organic tertiary amine base or inorganic base. The resulting sulfonamide derivative 8 is isolated by aqueous work-up, extraction into an appropriate organic solvent, and solvent removal.

Step 7 involves the deprotection of the ester protecting group of compound 8 to give carboxylic acid 9. In the cases where a silyl ester is utilized, deprotection is accomplished by maintaining a mixture of the ester and methanol, ethanol, isopropanol, or another alcohol solvent at 20°C to reflux and isolating the product by filtration or solvent removal. Alternatively, silyl esters can be deprotected by treatment with mineral acid or acetic acid in either organic or aqueous solution or by treatment with fluoride ion in organic solution.

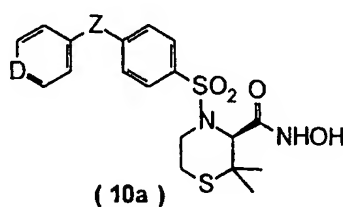
In the cases where a carbon ester is utilized, the ester can be removed by heating a mixture of compound 8 and hydrogen chloride, sulfuric acid, or other mineral in water, dioxane or another suitable organic solvent at reflux. Alternatively, the ester can be removed by treatment with sodium hydroxide, lithium hydroxide, potassium hydroxide, or another suitable inorganic base in water or a combination of water and methanol, tetrahydrofuran, or another suitable organic solvent. In the case where Q is allyl, the ester can be removed by treatment with N-methylaniline, morpholine, or another suitable secondary amine and tetrakis(triphenylphosphine)palladium(0) or another suitable palladium(0) catalyst in ethyl acetate, acetonitrile, or another suitable organic solvent. In the case where Q is benzyl, the ester can be removed by catalytic hydrogenation.

The final step of the process is a two-step procedure involving in-situ activation of the carboxyl functionality of compound 9 and subsequent displacement with hydroxylamine or a suitable salt or derivative of hydroxylamine. The activation is accomplished by reaction of compound 9 with oxalyl chloride or thionyl chloride with or without N,N-dimethylformamide present as catalyst in dichloromethane, acetonitrile, or other suitable solvent to give the corresponding acid chloride. Alternatively, the carboxyl can be activated by addition of methanesulfonyl chloride, isobutylchloroformate or various other chloroformate reagents, 1,3-dicyclohexylcarbodiimide or other carbodiimide reagents. The activated compound is added to hydroxylamine or a suitable salt or derivative of hydroxylamine and an appropriate organic or

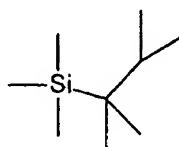
- 53 -

inorganic base, if necessary, in water, tetrahydrofuran, dioxane, dimethoxyethane, tert-butyl alcohol, dichloromethane, or other suitable solvent or solvent combinations. The resulting hydroxamic acid **10** can be isolated by solvent removal or by dissolution in aqueous hydroxide, adjusting the pH to 5 to 10 range, and collecting the precipitate by filtration.

A preferred compound is 3(S)-N-hydroxy-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide, illustrated by the structural formula:



A preferred carboxylic acid protecting group, Q, is dimethylthexylsilyl, where A is silicon, R₈ and R₉ are both CH₃, and R₁₀ is (CH₃)₂CHC(CH₃)₂, illustrated by the following structural formula:



Other compounds of the formula 1 may be prepared by methods known to those skilled in the art in a manner analogous to the general procedures described above. Specific examples of methods used to prepare the inventive compounds are described below along with illustrative preferred embodiments of the inventive compounds of the formula 1, 1-a, 1-f or 1-g, or their pharmaceutically acceptable prodrugs, salts or solvates.

The following specific examples are intended to be illustrative of the invention and should not be construed as limiting the scope of the invention as defined by the appended claims. These examples include preferred embodiments of the inventive compounds.

Example 1. Process for the preparation of 3(S)-N-hydroxy-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide

1(a) Via the intermediate 3(S)-dimethylthexylsilyl 2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate

Step 1. Preparation of 4-Phenoxypyridine

Phenol (2.82 kg, 30.0 mol) was heated to 50 °C and 4-chloropyridine hydrochloride (1.5 kg, 10.0 mol) was added. The resulting solution was heated at 150°C for 15 hours. The dark amber solution was cooled to 25°C then poured into 3 M aqueous sodium hydroxide (16 L). The aqueous was extracted with dichloromethane (3 x 4 L). The combined organic was washed with 1 M sodium hydroxide (2 x 4 L), water (4 L), and brine (4 L) then dried over sodium sulfate and filtered. The solvent was removed under vacuum and the residual oil was dissolved in hexanes (6 L). The mixture was cooled to -60°C with stirring and the resulting solid was collected by filtration and dried to give 1.1 kg of 4-phenoxypyridine (64% yield). mp 46-49°C. ¹H NMR (300 MHz, CDCl₃) δ 8.45 (dd, J = 1.5, 8 Hz, 2H), 7.41 (dd, J = 12, 12 Hz, 2H), 7.28 (dd, J = 12, 1H), 7.06 (d, J = 12 Hz, 2H), 6.84 (dd, J = 1.5, 8 Hz, 2H).

Step 2. Preparation of 4-[(Pyrid-4-yl)oxy]benzenesulfonic acid 3a

To a vigorously stirred solution of 4-phenoxypyridine (1 kg) in dry 1,2-dichloroethane (3 L) at -10°C under a stream of argon, chlorosulfonic acid (974 mL) was added slowly. The addition rate of the chlorosulfonic acid was adjusted to keep the reaction temperature below 0°C. After half of the chlorosulfonic acid was added, the exotherm stopped. The cooling bath was removed and the addition of chlorosulfonic acid continued over 3 hours while the reaction solution warmed to room temperature. While continually purging with inert gas, the vigorously stirred reaction mixture was heated to 45°C. By thin layer chromatography analysis, no more starting material remained after 20 hours.

- 55 -

The reaction mixture was cooled to room temperature and slowly poured into ice cold water (5 L) while stirring. Potassium phosphate tribasic (212 g) was added as a solid to the mixture and this was stirred for 10 minutes followed by addition of sodium hydroxide (2M) to pH 2. After stirring for 1 hour, the pH was changed to 7 by the addition of sodium hydroxide (2M). Agitation was continued for 5 minutes then the organic layer was drained off and discarded. The mixture was extracted a second time with dichloromethane (2L), the mixture agitated for 5 minutes, and the organic layer drained off and discarded. The remaining aqueous mixture was extracted by addition of dichloromethane (6 L), tetrabutylammonium bromide (940 g), and sodium hydroxide (2M) to pH 7. The mixture was agitated for 5 minutes and the organic layer (bottom) drained into a flask. The extraction procedure was repeated twice. The combined organic was dried over magnesium sulfate, filtered, and the solution was concentrated under vacuum to an oil. The residual oil was diluted with 20% ethanol in ethyl acetate (8 L, dry), and hydrogen chloride gas added to a pH of 1. The solid was filtered off and the filter cake rinsed with 20% ethanol in ethyl acetate (2L). The solid was dried under vacuum at 45°C for 15 hours to yield 4-[(pyrid-4-yl)oxy]benzenesulfonic acid **3a** (1.3 kg) as a white powdery solid.

mp dec. >275 °C

Anal. calc. for $C_{11}H_9NO_4S$: C, 52.58; H, 3.61; N, 5.57; S, 12.76. Found: C, 52.50; H, 3.69; N, 5.51; S, 12.67.

1H NMR (300 MHz, DMSO- d_6): δ 8.86 (dd, J = 1.5, 7.4 Hz, 2H), 7.84 (dd, J = 1.5, 7 Hz, 2H), 7.54 (dd, J = 1.5, 7.4 Hz, 2H), 7.35 (dd, J = 1.5, 7 Hz, 2H).

Step 3. Preparation of 4-[(pyrid-4-yl)oxy]benzenesulfonyl chloride hydrochloride **4a**

To a suspension of 4-[(pyrid-4-yl)oxy]benzenesulfonic acid **3a** (1.3 kg) in acetonitrile (8 L), was added N,N-dimethylformamide (12.35 mL) and the viscous reaction mixture was heated to 75 °C. Thionyl chloride (756 mL) was added to the reaction mixture over 30 minutes. The reaction mixture

- 56 -

slowly became less viscous and became homogeneous after 45 minutes, which indicated the reaction was complete. A portion of the solvent (4 L) was evaporated under vacuum and tert-butyl methyl ether (4 L) was added. The resulting slurry was filtered under inert atmosphere. The filter cake was rinsed with tert-butyl methyl ether (2 L) and the solid dried under vacuum to yield 4-[(pyrid-4-yl)oxy] benzenesulfonyl chloride hydrochloride **4a** (1.35 kg) as a fluffy off-white solid of pearlescent flakes: mp 182 °C; ¹H NMR (300 MHz, CDCl₃): δ 8.87 (d, *J* = 7 Hz, 2H), 8.24 (d, *J* = 8.5 Hz, 2H), 7.50 (d, *J* = 8.5 Hz, 2H), 7.43 (d, *J* = 7 Hz, 2H).

Steps 4 and 5. Preparation of 3(S)-dimethylthexylsilyl 2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate

Under argon atmosphere, D-penicillamine (375 g, 2.51 mol) was suspended in dry N,N-dimethylformamide (3.8 L) and 1,8-diazabicyclo [5.4.0]undec-7-ene (413 mL, 2.76 mol) was added, forming a clear solution. While the temperature was kept between 20-30°C, dimethylthexylsilyl chloride (543 mL, 2.76 mol) was added dropwise. After stirring for 1.5 hours, 1,2-dichloroethane (593 mL, 7.53 mol) was added in one portion. 1,8-diazabicyclo [5.4.0]undec-7-ene (788 mL, 5.27 mol) was added over 1 hour, keeping the temperature between 25-30°C. The resulting mixture was stirred at 20°C for 3 hours then quenched into a 0°C mixture of water (8 L), tert-butyl methyl ether (2 L), and hexanes (2 L). After stirring 5 minutes, the phases were separated and the aqueous was extracted with additional tert-butyl methyl ether (2 L) and hexanes (2 L) mixture. The combined organic layers were dried over magnesium sulfate, filtered, and the solvent removed under vacuum to give 878 g (110% yield) of crude 3(S)-dimethylthexylsilyl 2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate as a thick, yellow oil. ¹H NMR (300 MHz, CDCl₃) δ 3.65 (s, 1H), 3.42-3.37 (m, 1H), 2.98-2.83 (m, 2H), 2.30-2.22 (m, 1H), 1.69-1.58 (m, 1H), 1.42 (s, 3H), 1.31 (s, 3H), 0.92-0.86 (m, 12H), 0.34 (s, 3H), 0.30 (s, 3H).

Steps 6 and 7. Preparation of 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid

Crude 3(S)-dimethylthexylsilyl 2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate (878 g, 2.51 mol) and 4-methylmorpholine (547 mL, 4.98 mol) were dissolved in dry dichloromethane (14 L) and the solution cooled to -20°C. 4-[(pyrid-4-yl)oxy]benzenesulfonyl chloride hydrochloride **4a** (690 g, 2.26 mol) was added and the mixture was warmed slowly to 20°C and maintained at 20°C for 12 hours. The resulting red suspension was poured into water (8 L). The phases were separated and the organic layer dried over sodium sulfate, filtered, and the solvent removed under vacuum, giving 1.4 kg (117% yield) of 3(S)-dimethylthexylsilyl 4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate as a red oil which was used without purification or characterization.

The residual red oil was dissolved in methanol (14 L) and the solution was heated at reflux for 1 hour, forming a precipitate. The mixture was cooled to 4°C and the precipitate was collected by filtration, washed with methanol, and dried to give 575 g (62% yield) of 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid as a light pink solid: mp dec. >235°C; ¹H NMR (300 MHz, CDCl₃): δ 8.60 (dd, *J* = 1.5, 5 Hz, 2H), 7.86 (d, *J* = 8.5, 2H), 7.39 (d, *J* = 9 Hz, 2H), 7.11 (dd, *J* = 1.5, 5 Hz, 2H), 4.3 (s, 1H), 4.03 (d, *J* = 12.5 Hz, 1H), 3.75 (ddd, *J* = 2.2, 13, 13 Hz, 1H), 3.02 (ddd, *J* = 3, 12.5, 13 Hz, 1H), 2.62 (d, *J* = 14 Hz, 1H), 1.52 (s, 3H), 1.35 (s, 3H).

Step 8. Preparation of 3(S)-N-hydroxy-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide

A suspension of 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid (700 g, 1.71 mol) in dichloromethane (7 L) was cooled to -65°C. Oxalyl chloride (179 mL, 2.05

- 58 -

mol) was added rapidly. The cooling bath was removed and the mixture was stirred at 20°C for 15 hours. The resulting solution was added over 1.25 hours to a solution of hydroxylamine (1.05 L of 50% aqueous solution, 17.15 mol) in tetrahydrofuran (3.5 L) and tert-butyl alcohol (1.8 L), keeping the temperature between 5 and 20°C. The resulting mixture was stirred at 20°C for 15 hours then poured into 1 M aqueous sodium hydroxide (10 L) at 5°C. The phases were separated and the aqueous was extracted with tert-butyl methyl ether (4 L). The aqueous layer was filtered through Celite and the pH adjusted to 8.5 by adding saturated aqueous ammonium chloride and concentrated hydrochloric acid. The resulting suspension was stirred for 3 hours. The solid was collected by filtration, washed with water, and dried to give 665 g (92% yield) of crude product. The crude material was recrystallized from a mixture of ethanol, water, and dichloromethane to give 466 g (70% recovery) of 3(S)-N-hydroxy-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide as a white, crystalline solid: mp 184-186° with gas evolution; ¹H NMR (300 MHz, DMSO-d₆): δ 10.69 (d, J = 1.5 Hz, 1H), 8.93 (d, J = 1.5 Hz, 1H), 8.57 (dd, J = 1.5, 4.5 Hz, 2H), 7.83 (dd, J = 2, 7 Hz, 2H), 7.37 (dd, J = 2, 7 Hz, 2H), 7.11 (dd, J = 1.5, 4.5 Hz, 2H), 4.06 (s, 1H), 4.07 (ddd, J = 2.5, 12.5, 12.5 Hz, 1H), 3.91 (ddd, J = 3, 2.2, 12 Hz, 1H), 2.98 (ddd, J = 3.7, 13, 13.5 Hz, 1H), 2.7-2.55 (m, 1H), 1.49 (s, 3H), 1.22 (s, 3H).

Example 1(b) Via t-Butyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate

Step 4A. 3(S)-2,2-Dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid 11

To a stirred suspension of D-penicillamine (14.92 g), in 1,2-dichloroethane (300 mL) and N,N-dimethylformamide (2 mL) at 0 °C was added 1,8-diazabicyclo [5.4.0]undec-7-ene (22.4 mL), followed by trimethylsilyl chloride (19.0 mL). The reaction mixture was stirred for 3 hours, slowly warming to room temperature. To the homogeneous solution 1,8-diazabicyclo[5.4.0]undec-7-ene (29.9 mL) was added over 10 minutes and

- 59 -

the reaction warmed to 47 °C. The reaction mixture was cooled to room temperature and was stirred an additional 17.5 hours. Methanol (10 mL) was added to the reaction mixture and a precipitate formed after stirring for 10 minutes. The reaction mixture was filtered and the precipitated material rinsed with a minimum amount of methanol. The solid was dried under vacuum at 50 °C for 6 hours to yield 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid (16.18 g) as a white powdery solid: mp dec. > 212°C; ¹H NMR (300 MHz, D₂O): δ 3.71(s, 1H), 3.68-3.60 (m, 1H), 3.27-3.01 (m, 2H), 2.78-2.64 (m, 1H), 1.45 (s, 3H), 1.42 (s, 3H).

Step 4a was also performed as follows:

To a stirred suspension of D-penicillamine (14.92 g), in 1,2-dichloroethane (150 mL) and dimethyl formamide (15 mL) at room temperature, was added trimethyl silyl chloride (19.0 mL) over 30 minutes and the reaction warmed to 43 °C. To the resulting viscous suspension 1,8-diazabicyclo[5.4.0.]undec-7-ene (22.4 mL) was added at a constant rate over 4 hours, and during the addition the reaction warmed to 48 °C. The reaction mixture slowly cooled to room temperature and was stirred an additional 2 hours. Isopropanol (75 mL) was added to the reaction mixture and this mixture was stirred for 3 hours while a precipitate formed. The reaction mixture was filtered and the precipitated material rinsed with isopropanol (100 mL). The solid was dried under vacuum at 50 °C for 6 hours, to yield the product 3(S)-2,2-Dimethyl-thiomorpholine-3-carboxylic acid (15.47 g) as a white powdery solid.

Step 5A. Preparation of t-butyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate.

A single neck 2.0 L flask was charged with dioxane (320 mL) and 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid (28.0 g, 0.16 mol.). The suspension was cooled to 0° C before adding concentrated sulfuric acid (32 mL, 0.6 mol.) via addition funnel over 10 minutes. Cooling

- 60 -

was removed and liquid isobutylene (200 mL, 2.2 mol.) was added to the suspension. (Isobutylene was condensed in a separate graduated cylinder at -20° C from a 400 g lecture bottle.) The gas was refluxed at room temperature with a double jacket condenser using -50° C ethanol from a recirculating cryobath. Stirring was continued for 19 hours before work-up. The reaction was poured into a cold, biphasic mixture containing ethyl acetate (400 mL) and 2 M sodium bicarbonate solution (1 L). The organics were isolated and the aqueous was back extracted with ethyl acetate (200 mL). The combined organics were washed with brine and dried over sodium sulfate. After filtration, the solvent was concentrated under vacuum to give t-butyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate as an oil that solidified on standing. (32.7g, 89% yield): ¹H NMR (300 MHz, CDCl₃) 3.42 (s, 1H), 3.2-3.35 (m, 1H), 2.7-2.85 (m, 2H), 2.05-2.2 (m, 1H), 1.37 (s, 6H), 1.3 (s, 3H), 1.2 (s, 3H).

Step 6. t-Butyl 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate

3(S)-t-Butyl 2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate (2.31 g, 0.01 mol) was combined with methylene chloride (25 mL) and 4-methylmorpholine (2.42 mL, 0.022 mol) to form a solution. To this solution was added 4-[(pyrid-4-yl)oxy]benzenesulfonyl chloride hydrochloride (3.22 g, 0.0105 mol). The reaction became an orange suspension accompanied by a mild exotherm. The reaction was poured into ethyl acetate (300 mL) after stirring 4 hours at room temperature. The organics were washed with 2N sodium hydroxide (50 mL) and brine solution (50 mL) before drying over sodium sulfate. The solution was filtered then concentrated under vacuum to give t-butyl 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate as a yellow solid (4.4 g, 94 % yield). ¹H NMR (300 MHz, CDCl₃) 8.55 (d, 2H), 7.80 (dd, 2H), 7.17 (dd, 2H), 6.92 (dd, 2H), 4.37 (s, 1H), 4.07 (dd, 1H), 3.89 (dt, 1H), 3.15 (dt, 1H), 2.45 (d, 1H), 1.63 (s, 3H), 1.36 (s, 3H), 1.33 (s, 9H).

Step 7. Preparation of 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid hydrochloride

A 100 mL flask was charged with dioxane (20 mL) and 3(S)-t-Butyl 4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate (4.37 g, 0.0094 mol). To this was added 4 M hydrogen chloride in dioxane (20 mL, 0.08 mol) and the mixture was heated to reflux. After 4 hours at reflux, the reaction mixture was cooled and filtered to give 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid hydrochloride (3.6 g, 81%) as a white solid. ¹H NMR (300 MHz, CDCl₃) 8.82 (d, 2 H), 8.15 (d, 2 H), 7.5-7.6 (m, 4 H), 4.4 (s, 1 H), 4.15 (dd, 1 H), 3.85 (dt, 1 H), 3.16 (dt, 1 H), 2.55 (d, 1 H), 1.64 (s, 3 H), 1.39 (s, 3 H).

Example 1(c) Via Methyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate

Step 5. Preparation of methyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate.

To a stirred solution of 1,2-dibromoethane (1.03 mL) in 10 mL of dry N,N-dimethylformamide at 25 °C was added over one hour via cannula, a solution D-penicillamine methyl ester hydrochloride (2.0 g), and 1,8-diazabicyclo [5.4.0]undec-7-ene (4.5 mL) in 20 mL of dry N,N-dimethylformamide. The reaction was stirred for 2 hours, then poured into sodium bicarbonate solution and extracted with ethyl acetate (3 x 100 mL), the organic fractions were combined, dried over sodium sulfate, filtered, isooctane added and the solvent removed. The residue was placed under vacuum for 24 hours to give methyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate (1.41 g) as a slightly yellow oil: ¹H NMR (300 MHz, CDCl₃): δ 3.68(s, 1H), 3.67(s, 3H), 3.39-3.30(m, 1H), 2.95-2.80(m, 2H), 2.31-2.18(m, 1H), 1.38(s, 3H), 1.27(s, 3H).

Step 6. Preparation of methyl 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate

To a solution of methyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate (0.756 g) in dichloromethane (20 mL) at room temperature was added 4-methylmorpholine (0.44 mL), followed by 4-[(pyrid-4-yl)oxy]benzenesulfonyl chloride hydrochloride 4a (1.28 g). The reaction was stirred for 24 hours then poured into pH 7 buffer (100 mL) and extracted with ethyl acetate (3 x 100 mL). The combined organic extracts were dried over sodium sulfate, filtered, and the solvent removed under vacuum. The residue was chromatographed on silica, eluting with 40% ethyl acetate in dichloromethane. The product-containing fractions were combined and the solvent removed. A minimum of dichloromethane was added followed by hexanes. The solvent was slowly removed which caused crystallization of methyl 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyltetrahydro-2H-1,4-thiazine-3-carboxylate (1.06 g) as a crystalline white solid: mp 151°C; ¹H NMR (300 MHz, CDCl₃): δ 8.55(dd, J = 1.5, 5 Hz, 2H), 7.76 (dd, J = 2, 6.5 Hz, 2H), 7.17 (dd, J = 2, 6.5 Hz, 2H), 6.89 (dd, J = 1.5, 5 Hz, 2H), 4.47 (s, 1H), 4.10 (ddd, J = 1.5, 1.7, 12.5 Hz, 1H), 3.79 (ddd, J = 3, 12.5, 12.5 Hz, 1H), 3.46 (s, 3H), 3.18 (ddd, J = 4, 13, 13.5 Hz, 1H), 2.48 (ddd, J = 2.5, 3, 14 Hz, 1H), 1.65 (s, 3H), 1.29 (s, 3H).

Step 7. Preparation of 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid

A solution of methyl 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate (15 g, 35.5 mmol) in 6 M aqueous hydrochloric acid (74 mL) was heated at reflux for 15 hours. The mixture was cooled slightly and the pH adjusted to 6 by addition of 3 M aqueous sodium hydroxide and 50% aqueous sodium hydroxide. The resulting suspension was cooled to 20°C and the precipitate collected by filtration, washed with water (200 mL), and dried to give 3(S)-4-(4-((pyrid-4-

- 63 -

yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid (9) as a white solid weighing 13.3 g (92% yield).

Example 1(d) Via Allyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate

Step 5a. Preparation of allyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate 7

A 50 mL flask was equipped with heating mantle, Dean-Stark trap, and reflux condenser and charged with 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid **11** (0.87 g, 0.005 mol). To this was added benzene (20 mL), p-toluenesulfonic acid monohydrate (0.856 g, 0.0045 mol), and sulfuric acid (0.14 mL, 0.0025 mol). The reaction was refluxed for 16 hours to give an amber solution while 0.2 ml of water was azeotroped. Heating was removed, and the reaction was poured into water (25 mL). The aqueous layer was separated and combined with methylene chloride (25 mL). The pH was adjusted from 1 to 9 with 1N sodium hydroxide solution. The organic was dried and the solvent removed under vacuum to give allyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate as a colorless oil (0.47 g, 44% yield). ¹H NMR (300 MHz, CDCl₃) 1.24 (s, 3 H), 1.42 (s, 3H), 2.3-2.36 (d, 1H), 2.8-2.9 (dt, 1H), 2.92-3.1 (dt, 1H), 3.3-3.4 (m, 1H), 3.65 (s, 1H), 4.7 (d, 2H), 5.3-5.5 (m, 2H), 5.8-6.1 (m, 1H).

Step 6. Preparation of allyl 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate

4-[(4-Pyridyl)oxy]benzenesulfonyl chloride hydrochloride **4a** (610 mg, 2.0 mmol) was suspended in dry acetonitrile (10 mL) and potassium carbonate (550 mg, 4.0 mmol) was added. After stirring for 30 minutes, a solution of allyl 3(S)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate (430 mg, 2.0 mmol) in acetonitrile (5 mL) was added dropwise over 15 minutes. The mixture was stirred at 20°C for 24 hours. The reaction was quenched into pH 7 buffer and the pH adjusted to 7 with 2 M hydrochloric

- 64 -

acid. The mixture was extracted with methylene chloride (2 x 25 mL). The combined organic layers were washed with brine, dried over sodium sulfate, and filtered. The solvent was removed under vacuum, giving allyl 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate as a yellow solid weighing 700 mg (78% yield). ¹HNMR (300 MHz, CDCl₃) 8.53 (d, *J* = 5 Hz, 2H), 7.78 (d, *J* = 8 Hz, 2H), 7.15 (d, *J* = 8 Hz, 2H), 6.90 (d, *J* = 8 Hz, 2H), 5.84-5.71 (m, 1H), 5.30-5.22 (m, 2H), 4.49 (s, 1H), 4.35 (d, *J* = 5 Hz, 2H), 4.10 (ddd, *J* = 1.5, 1.5, 9 Hz, 1H), 3.78 (ddd, *J* = 1.5, 12, 12 Hz, 1H), 3.18 (ddd, *J* = 1.5, 12, 12 Hz, 1H), 2.43 (ddd, *J* = 1.5, 1.5, 12 Hz, 1H), 1.65 (s, 3H), 1.31 (s, 3H).

Step 7. Preparation of 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid

To a solution of allyl 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate (0.150 g) in ethyl acetate (3 mL) at 0°C, was added N-methylaniline (0.071 mL) followed by tetrakis(triphenylphosphine)palladium(0) (0.0076 g). The reaction mixture was stirred for 2 hours at 0°C, hexanes added (4 mL), and the solid filtered off and dried in vacuo to give 3(S)-4-(4-((pyrid-4-yl)oxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid (0.085 g) as a white solid.

Example 2 Preparation of Intermediates of Formula 15

(a) 4-Phenoxybenzenesulfonyl chloride

To a stirred solution of 42.5 g (0.25 mol) of phenyl ether in 200 mL of dichloromethane at -20 °C under argon was slowly added 23.3 g (0.20 mol) of chlorosulfonic acid. After the addition was complete, the reaction was allowed to slowly warm to room temperature. After 16 hours, 150 mL of isooctane was added and the solution was concentrated to an oily residue. Redissolution in 200 mL of 1:3 dichloromethane/isooctane and reconcentration with cooling to about 100 mL gave a solid. The supernatant

- 65 -

was decanted, and the solid triturated with additional isooctane and then dried in vacuo to give 55.2 g of crude 4-phenoxybenzene sulfonic acid. The crude acid was dissolved in 200 mL of dichloromethane, and 22 mL (32 g, 0.25 mol) of oxalyl chloride was added, followed by 2.5 mL of N,N-dimethylformamide. After 2 days, the reaction solution was poured into 200 mL of ice water, and extracted with 400 mL of hexane. The organic layer was washed with 100 mL of water and 100 mL of brine, dried over magnesium sulfate, and concentrated. Recrystallization of the residue from dichloromethane/isooctane gave 38.5 g of 4-phenoxybenzenesulfonyl chloride as a white solid: mp 41.5 °C; ¹H-NMR (CDCl₃) δ 7.10 (apparent t, 4 H, J = 7 Hz), 7.28 (t, 1H, J = 7 Hz), 7.46 (t, 2H, J = 8 Hz), 7.98 (d, 2H, J = 8.8 Hz).

(b) 4-(4-Methylphenoxy)benzenesulfonyl chloride

To a solution of 1.84 g (10.0 mmol) of 4-methyldiphenyl ether (see *J. Chem Soc., Perkin Trans. 1*, **1992**, 407-408) with 2 mL of dichloromethane in an ice-bath was added a solution of chlorosulfonic acid (0.73mL, 11.0 mmol) in 2 mL of dichloromethane dropwise. The resulting mixture was stirred at 0°C to room temperature for 2 hours, and then oxalyl chloride (11.14mL, 13.0 mmol) was added dropwise, followed by 0.15 mL of DMF. The resulting mixture was heated to 40°C for 1 hour and then allowed to cool to room temperature over a 2 hour period. The reaction mixture was poured into ice-pH 7 phosphate buffer (50mL), then extracted with EtOAc:Hexane (4:3) (3x150mL). The combined organic layers were washed with brine (75mL). The aqueous layer was extracted with EtOAc/Hexane(4:3) (150mL). The organic layer was dried over Na₂SO₄, then evaporated by vacuum to give crude product as white solid. This solid was triturated with hexane and collected by filtration, then dried under high vacuum to give 1.555 g (57%) of 4-(4-methylphenoxy)benzenesulfonyl chloride as white solid: mp 295-300°C; ¹H-NMR (DMSO-d₆) δ 2.34 (s, 3H), 6.91-6.99 (dd, J = 7.7,8.4Hz, 4H), 7.24-7.27 (d, J = 8.4Hz, 2H), 7.61-7.63 (d, J = 8.1Hz, 2H).

- 66 -

Anal. calc. for $C_{13}H_{11}O_3SCl$: C, 55.22; H, 3.92; S, 11.34; Cl, 12.71. Found: C, 55.06; H, 3.95; S, 11.28; Cl, 12.71.

The following were prepared in a similar fashion:

(c) 4-(4-Bromophenoxy)benzenesulfonyl chloride

Prepared from 4-bromobiphenyl ether (Aldrich), mp 81 °C.

(d) 4-(4-Chlorophenoxy)benzenesulfonyl chloride

Prepared from 4-chlorobiphenyl ether (Transworld), mp 61 °C.

(e) 4-(4-Fluorophenoxy)benzenesulfonyl chloride

Prepared from 4-fluorobiphenyl ether (Riedel-de Haen), mp 76°C.

(f) 4-(4-Cyanophenoxy)benzenesulfonyl chloride

Prepared from 4-cyanobiphenyl ether (Transworld).

(g) 4-(4-Methoxyphenoxy)benzenesulfonyl chloride

Prepared from 4-methoxybiphenyl ether (which was prepared from 4-hydroxybiphenyl ether by methylation with methyl iodide and potassium carbonate in refluxing acetone).

(h) 4-(Pyrid-2-yl)oxybenzenesulfonyl chloride

Prepared from 2-phenoxy pyridine (ICN): 1H NMR ($CDCl_3$) δ 8.25 (m, 1H), 8.05 (d, 2H, $J = 9$ Hz), 7.81 (t, 1H, $J = 8$ Hz), 7.34 (d, 2H, $J = 9$ Hz), 7.15 (dd, 1H, $J = 7$ & 5 Hz), 7.06 (d, 1H, $J = 8$ Hz).

Example 3.

(a) 3(S)-N-hydroxy-4-(4-(4-(imidazol-1-yl)phenoxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide.

This compound was prepared in a manner similar to the procedure described in Example 1(d), except that 4-(imidazol-1-yl)biphenyl ether (prepared by the procedure described in U.S. Patent 4,006,243, the disclosure of which is incorporated herein by reference) was used in place of 4-phenoxy pyridine: mp 148-150 °C.

(b) 3(S)-N-hydroxy-4-(4-(4-chlorophenoxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide.

This compound was prepared in a manner similar to the procedure described in Example 1(d), except that 4-(4-chlorophenoxy)benzenesulfonyl chloride (Example 2(d)) was employed in place of 4-[(4-pyridyl)oxy]benzenesulfonyl chloride hydrochloride in step 6: mp 178-180°C.

Anal. Calcd for $C_{19}H_{21}N_2O_5S_2Cl \cdot 0.3H_2O$: C, 49.94; H, 4.63; N, 6.13; S, 14.03; Cl, 7.76. Found: C, 48.34; H, 4.77; N, 6.96; S, 13.35; Cl, 7.46.

(c) 3(S)-N-hydroxy-4-(4-((pyrid-4-yl)sulfanyl)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide.

This compound was prepared in a manner similar to the procedure described in Example 1(d), except that thiophenol was employed in place of phenol (in example 1(a), step 1): mp 129-131°C with gas evolution; 1H NMR (300 MHz, DMSO- d_6) δ 10.70 (s, 1H), 8.92 (s, 1H), 8.48 (dd, J = 1.5, 6 Hz, 2H), 7.83 (d, J = 8.5 Hz, 2H), 7.74 (d, J = 8.5 Hz, 2H), 7.25 (dd, J = 1.5, 6 Hz, 2H), 4.15-4.00 (m, 1H), 4.06 (s, 1H), 3.97-3.85 (m, 1H)

Example 4

2(R/S)-N-hydroxy-1-(4-(4-bromophenoxy)benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide

Step 1. A solution of 2(R/S)-piperazine-2-carboxylic acid dihydrochloride (1.06 g, 5.23 mmol) in 8 mL of 1:1 dioxane:water was brought to pH 11 with 10% aqueous sodium hydroxide and then cooled to 0°C. To this solution was added a solution of di-t-butylidicarbonate (1.37 g, 6.28 mmol) in 3 mL of dioxane, and the reaction mixture was allowed to warm slowly to room temperature overnight. The reaction mixture was then re-cooled to 0°C, and triethylamine (4.0 mL) and 4-(4-bromophenoxy)benzenesulfonyl chloride (2.00 g, 5.75 mmol, as a solution in 3 mL of dioxane) was added. The reaction mixture was stirred for 5 hours at 0°C to room temperature, and then

acidified to pH 2.5 with 2 N hydrochloric acid. The mixture was extracted with ethyl acetate (3 x 100 mL) and the combined organic layers were washed with 1 N aqueous sodium hydrogen sulfate and brine, dried over sodium sulfate, and concentrated. The residue was purified by chromatography on 200 g of silica, eluting with 1:10:1 ethyl acetate:hexane:acetic acid, to give 1.07 g (38%) of 2(R/S)-1-(4-(4-bromophenoxy) benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxylic acid: mp 112.8°C.

Step 2. To a solution of 2(R/S)-1-(4-(4-bromophenoxy)benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxylic acid (2.42 g, 4.47 mmol) in 15 mL of anhydrous dichloromethane at 0°C was added O-(t-butyl-dimethylsilyl)hydroxylamine (998 mg, 6.71 mmol), followed by a solution of EDC methiodide (1.99 g, 6.71 mmol) in 20 mL of dichloromethane. The resulting mixture was stirred for 16 hours at 0°C to room temperature, and then concentrated *in vacuo*. The residue was partitioned between ethyl acetate and water, and the organic layer was washed with water, saturated aqueous sodium bicarbonate, and brine. After drying over sodium sulfate, the organic layer was concentrated, and the residue was purified by rapid filtration through a pad of silica gel, eluting with 1:1 ethyl acetate:hexane. After concentration of the filtrate, the residue was triturated with hexane, filtered, and dried under vacuum to give, in two crops, 1.78 g (61%) of 2(R/S)-N-(t-butyl-dimethylsilyloxy)-1-(4-(4-bromophenoxy)benzene-sulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide as a white solid: mp 163.6°C.

Step 3. To a solution of 2(R/S)-N-(t-butyl-dimethylsilyloxy)-1-(4-(4-bromophenoxy)benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide (1.599 g, 2.38 mmol) in 8 mL of anhydrous THF was added a 1 M solution of tetrabutylammonium fluoride in THF (3.6 mL). After 0.5 hours, the reaction mixture was concentrated and the residue was partitioned between ethyl acetate and water. The organic layer was washed with saturated aqueous sodium bicarbonate and brine, dried over sodium sulfate, and concentrated. Trituration of the residue with t-butyl methyl ether:hexane

gave a precipitate which was filtered and dried under vacuum to give 1.320 g (99%) of 2(R/S)-N-hydroxy-1-(4-(bromophenoxy)benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide: mp 112.4°C. Anal. calc. for $C_{22}H_{26}BrN_3O_7S$: C, 47.49; H, 4.71; N, 7.55; Found: C, 47.56; H, 5.01; N, 7.42.

Example 5

(a) 2(R/S)-N-hydroxy-1-(4-(4-bromophenoxy)benzenesulfonyl)-piperazine-2-carboxamide hydrochloride

2(R/S)-N-hydroxy-1-(4-(4-bromophenoxy)benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide (999.1 mg, 1.80 mmol) was dissolved in 40 mL of 4:3:1 ethyl acetate/dichloro-methane/methanol with gentle heating. The resulting clear solution was allowed to cool to room temperature, and 5 mL of 4 M hydrogen chloride in dioxane was added. After 5 hours, the reaction mixture was partially concentrated under reduced pressure, and then diluted with ethyl acetate:ethyl ether. The precipitate was collected by filtration, washed with ethyl acetate and ethyl ether, and dried under vacuum to give 548.8 mg (62%) of 2(R/S)-N-hydroxy-1-(4-(4-bromophenoxy) benzenesulfonyl)-piperazine-2-carboxamide hydrochloride as a white solid: mp 186.6°C.

Anal. calc. for $C_{17}H_{19}ClBrN_3O_5S$: C, 41.43; H, 3.89; N, 8.53; Found: C, 41.47; H, 3.96; N, 8.38.

The following compound was prepared in a similar manner:

(b) 2(R/S)-N-hydroxy-1-(4-phenoxybenzenesulfonyl)-piperazine-2-carboxamide: mp 160.4°C;

Anal. calc. for $C_{17}H_{19}N_3O_5S$: C, 54.10; H, 5.07; N, 11.13; S, 8.50; Found: C, 54.04; H, 5.09; N, 11.06; S, 8.44.

Example 6**(a) 2(R/S)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(N-methylcarbamoyl)-piperazine-2-carboxamide**

Step 1. To a suspension of 1.20 g of 2(R/S)-4-(benzyloxycarbonyl)-piperazine-2-carboxylic acid (obtained according to the method of M.E. Freed and J.R. Potoski, U.S. Pat. No. 4,032,639 (1977), the disclosure of which is herein incorporated by reference) in dichloromethane (2.5 mL) at 0°C was added 0.63 mL of trimethylsilyl chloride. After 10 minutes, triethylamine (1.55 mL) was added, followed by addition of 1.37 g of 4-(4-chlorophenoxy)benzene-sulfonyl chloride. After 3 hours, the mixture was partitioned between dichloromethane and pH 4 citrate buffer. The organic layer was washed with water, dried over sodium sulfate, and concentrated. The residue was purified by chromatography, eluting with 0.5% acetic acid in 95:5 dichloromethane/ethanol, to provide 2.05 g (85%) of 2(R/S)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(benzyloxycarbonyl)-piperazine-2-carboxylic acid: mp 104.2°C.

Anal. calc. for $C_{25}H_{23}ClN_2O_7S$: C, 56.55; H, 4.37; N, 5.28; S, 6.04; Found: C, 56.65; H, 4.41; N, 5.22; S, 6.10.

Step 2. A solution of 2(R/S)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(benzyloxycarbonyl)-piperazine-2-carboxylic acid (2.21 g) in 18:1:1 ethanol:ethyl acetate:water was hydrogenated at 1 atm over 10% Pd/C (0.22g) for 1 day. The catalyst was removed by filtration and the solution concentrated to give 2(R/S)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxylic acid of ca. 95% purity, which was used without further purification.

Step 3. To a solution of 2(R/S)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxylic acid (0.987 g) and triethylamine (0.41 mL) in 20 mL of anhydrous DMF was added methyl isocyanate (0.16 mL). After 6 hours, the reaction was partitioned between dichloromethane and 1 N sodium bisulfate. The aqueous layer was extracted twice more with dichloromethane, and the combined organic layers were dried (sodium sulfate) and

- 71 -

concentrated. The residue was purified by chromatography, eluting with 85:15 dichloromethane:ethanol containing 0.5% acetic acid, to provide 0.918 g (81%) of 2(R/S)-1-(4-(4-chlorophenoxy) benzenesulfonyl)-4-(N-methylcarbamoyl)-piperazine-2-carboxylic acid: mp 212.7°C. Anal. calc. for $C_{19}H_{20}ClN_3O_6S$: C, 50.27; H, 4.44; N, 9.26; S, 7.06; Found: C, 50.56; H, 4.40; N, 9.38; S, 6.93.

Step 4. To a solution of O-(t-butyldimethylsilyl)hydroxylamine (0.282 g) in 12 mL of 5:1 dichloromethane:DMF at 0°C was added 0.580 g of 1-(4-(4-chlorophenoxy) benzenesulfonyl)-4-(N-methylcarbamoyl)-2R/S-piperazinecarboxylic acid followed by EDC hydrochloride (0.294 g) and the reaction mixture was stirred for 15 minutes at 0°C and then allowed to warm to room temperature. After 1.5 hours, the reaction was partitioned between ethyl acetate and aqueous sodium bicarbonate. The organic layer was washed with water and brine, dried over sodium sulfate, and concentrated. The residue was crystallized by slow evaporation from dichloromethane/t-butyl methyl ether/isooctane to provide 0.643 g (86%) of 2(R/S)-N-(t-butyldimethylsilyloxy)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(N-methylcarbamoyl)-piperazine-2-carboxamide as a white solid: mp 171.0°C.

Anal. calc. for $C_{25}H_{35}ClN_4O_6SSi$: C, 51.49; H, 6.05; N, 9.61; S, 5.50; Found: C, 51.59; H, 6.06; N, 9.67; S, 5.58.

Step 5. To a solution of 2(R/S)-N-(t-butyldimethylsilyloxy)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(N-methylcarbamoyl)-piperazine-2-carboxamide in 20 mL of methanol at 25°C was added 0.5 mL of trifluoroacetic acid. After 30 minutes, 20 mL of toluene was added and the solution was concentrated. The residue was recrystallized from dichloromethane/t-butyl methyl ether/isooctane to give 781 mg (99%) of 2(R/S)-N-hydroxy-1-(4-(4-chlorophenoxy)-benzenesulfonyl)-4-(N-methylcarbamoyl)-piperazine-2-carboxamide as a white solid: mp 133.2°C.

Anal. calc. for $C_{19}H_{21}ClN_4O_6S$: C, 48.66; H, 4.51; N, 11.95; S, 6.84; Found C, 48.74; H, 4.53; N, 11.90; S, 6.91.

- 72 -

The following compounds can be prepared in a similar manner:

(b) 2(R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-4-(N-methylcarbamoyl)-piperazine-2-carboxamide;

(c) 2(R)-N-hydroxy-1-(4-(4-methoxyphenoxy)benzenesulfonyl)-4-(N-methylcarbamoyl)-piperazine-2-carboxamide; and

(d) 2(R/S)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(N-isopropylcarbamoyl)-piperazine-2-carboxamide.

Example 7

(a) 2(R/S)-N-hydroxy-1-(4-phenoxybenzenesulfonyl)-4-acetyl-piperazine-2-carboxamide

Step 1. To a stirred solution of 42.5 g (0.25 mol) of phenyl ether in 200 mL of dichloromethane at -20°C under argon was slowly added 23.3 g (0.20 mol) of chlorosulfonic acid. After the addition was complete, the reaction was allowed to slowly warm to room temperature. After 16 hours, 150 mL of isooctane was added and the solution was concentrated to an oily residue. Redissolution in 200 mL of 1:3 dichloromethane/isooctane and reconcentration with cooling to about 100 mL gave a solid. The supernatant was decanted, and the solid triturated with additional isooctane and then dried in vacuo to give 55.2 g of crude 4-phenoxybenzene sulfonic acid. The crude acid was dissolved in 200 mL of dichloromethane, and 34 g (0.25 mol) of oxalyl chloride was added, followed by 2.5 mL of DMF. After 2 days, the reaction solution was poured into 200 mL of ice water, and extracted with 400 mL of hexane. The organic layer was washed with 100 mL of water and 100 mL of brine, dried over magnesium sulfate, and concentrated. Recrystallization of the residue from dichloromethane/isooctane gave 38.5 g of 4-phenoxybenzenesulfonyl chloride as a white solid: mp 41.5°C.

Step 2. To a stirred solution of 2(R/S)-piperazine-2-carboxylic acid (1.30 g, 10.0 mmol) and triethylamine (3.6 mL) in 25 mL of 2:2:1 dioxane/water/acetonitrile at -20°C was added dropwise 1.13 mL (1.22 g, 12.0 mmol) of acetic anhydride. After 2 hours at -20°C, an additional 1.5 mL

- 73 -

of triethylamine was added, followed by 2.69 g (10 mmol) of 4-phenoxybenzenesulfonyl chloride. The reaction mixture was allowed to warm slowly to room temperature. After 18 hours, the reaction was partitioned between 100 mL of 0.5 N potassium dihydrogen phosphate and 100 mL of ethyl acetate. The aqueous layer was acidified with 10 mL of 2 M sulfuric acid, and extracted with an additional 100 mL of ethyl acetate. The combined organic layers were dried over sodium sulfate and concentrated. The residue was dissolved in 100 mL of 1:1 toluene/methanol, and trimethylsilyldiazomethane (2 M solution in hexane) was added dropwise until the yellow color no longer dissipated (about 15 mL). After addition of 2 drops of acetic acid to consume excess trimethylsilyl-diazomethane, the solution was concentrated and the residue was purified by chromatography on 150 g of silica gel, eluting with a 80% ethyl acetate/hexane to ethyl acetate gradient. Concentration of the product-containing fractions gave an oil which solidified upon trituration with t-butyl methyl ether/hexane to give 1.86 g (44%) of methyl 2(R/S)-1-(4-phenoxybenzenesulfonyl)-4-acetyl-piperazine-2-carboxylate: mp 118°C.

Anal. calc. for $C_{20}H_{22}N_2O_6S$: C, 57.41; H, 5.30; N, 6.69; S, 7.66;

Found: C, 57.38; H, 5.29; N, 6.75; S, 7.72.

Step 3. To a solution of methyl 2(R/S)-1-(4-phenoxybenzenesulfonyl)-4-acetyl-piperazine-2-carboxylate (1.672 g) in 12 mL of THF and 6 mL of methanol was added in a dropwise manner 4 mL of 2 N aqueous lithium hydroxide. After 1 hour, the reaction solution was partitioned between 100 mL of ethyl acetate and 25 mL of 1 N aqueous sodium bisulfate. The organic layer was washed with brine, dried over sodium sulfate, and concentrated. The residue was trituated with t-butyl methyl ether and filtered to give 1.544 g (96%) of 2(R/S)-1-(4-phenoxybenzenesulfonyl)-4-acetyl-piperazine-2-carboxylic acid as a white solid: mp 213°C.

Anal. calc. for $C_{19}H_{20}N_2O_6S$: C, 56.43; H, 4.98; N, 6.93; S, 7.93;

Found: C, 56.50; H, 4.96; N, 6.90; S, 8.01.

- 74 -

Step 4. To a solution of 0-(t-butyldimethylsilyl)hydroxylamine (0.575 g) in 13 mL of dichloromethane at 0°C was added 1.212 g of 2(R/S)-1-(4-phenoxybenzenesulfonyl)-4-acetyl-piperazine-2-carboxylic acid. To this mixture was added 2.0 mL of DMF, resulting in a clear solution. After about 3 minutes, EDC hydrochloride (0.634 g) was added in one portion, and the reaction was stirred for 15 minutes at 0°C and then allowed to warm to room temperature. After 2 hours, the reaction was partitioned between 100 mL of 3:1 ethyl acetate/hexane and 50 mL of water. The organic layer was washed with saturated aqueous sodium bicarbonate, 1 N aqueous sodium bisulfate, and pH 7 phosphate buffer/brine, dried and concentrated. Trituration of the residue with t-butyl methyl ether/hexane and filtration gave 1.351 g (84%) of 2(R/S)-N-(t-butyldimethylsilyloxy)-1-(4-phenoxy-benzenesulfonyl)-4-acetyl-piperazine-2-carboxamide as a white solid: mp 146°C.

Anal. calc. for $C_{24}H_{35}N_2O_6SSi$: C, 56.26; H, 6.61; N, 7.87; S, 6.01; Found: C, 56.33; H, 6.66; N, 7.94; S, 6.09.

Step 5. To a solution of 2(R/S)-N-(t-butyldimethylsilyloxy)-1-(4-phenoxybenzenesulfonyl)-4-acetyl-piperazine-2-carboxamide (1.200 g, 2.25 mmol) in 20 mL of methanol at 25° was added 0.5 mL of trifluoroacetic acid. After 1 hours, 20 mL of toluene was added and the solution was concentrated. The residue was recrystallized from dichloromethane/t-butyl methyl ether to give 850 mg (84%) of 2(R/S)-N-hydroxy-1-(4-phenoxybenzenesulfonyl)-4-acetyl-piperazine-2-carboxamide as a white solid: mp 171°C (decomp).

Anal. calc. for $C_{19}H_{21}N_3O_6S \cdot 0.25 C_5H_{12}O (t-BuOMe) \cdot 0.25 H_2O$: C, 54.63; H, 5.55; N, 9.44; S, 7.20; Found: C, 54.62; H, 5.45; N, 9.38; S, 7.20.

The following compounds can be prepared in a similar manner from enantiomerically pure 2(R)-piperazine-2-carboxylate:

(b) 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-acetyl-piperazine-2-carboxamide;

- 75 -

(c) 2(R)-N-hydroxy-1-(4-phenoxybenzenesulfonyl)-4-(methoxyacetyl)-piperazine-2-carboxamide:

(d) 2(R)-N-hydroxy-1-(4-phenoxybenzenesulfonyl)-4-(isobutyryl)-piperazine-2-carboxamide:

(e) 2(R)-N-hydroxy-1-(4-(pyrid-4-yl)oxybenzenesulfonyl)-4-acetyl-piperazine-2-carboxamide:

(f) 2(R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-4-acetyl-piperazine-2-carboxamide; and

(g) 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(dimethylaminoacetyl)-piperazine-2-carboxamide.

Example 8

(a) 3(R)-N-hydroxy-4-(4-(4-chlorophenoxy)benzenesulfonyl)-morpholine-3-carboxamide

Step 1. To mixture of D-serine methyl ester hydrochloride (11.20 g) and N-methylmorpholine (16.5 mL) in 385 mL of 10:1 dichloromethane:DMF at -10°C was added, in portions over a 2 hour period, 18.18 g of 4-(4-chlorophenoxy)benzenesulfonyl chloride. The mixture was stirred an additional 2.5 hours at -10°C, and then partitioned between 1 M aqueous sodium bisulfate (200 mL) and 4:1 ethyl acetate:hexane (400 mL). The aqueous layer was extracted with additional ethyl acetate:hexane (200 mL) and the combined organic layers were washed with water, 1 M aqueous sodium bisulfate, saturated aqueous sodium bicarbonate, and brine. After drying over sodium sulfate, the solution was concentrated almost to dryness, and the residue was crystallized from t-butyl methyl ether:dichloromethane:isooctane to give two crops of 18.09 g and 3.20 g. Total yield of N-(4-(4-chlorophenoxy)benzenesulfonyl)-D-serine methyl ester was 21.29 g; mp 103.9°C.

Step 2. To a stirred solution of N-(4-(4-chlorophenoxy)benzenesulfonyl)-D-serine methyl ester (8.3 g) and triphenyl phosphine (6.79 g) in 150

- 76 -

mL of THF was added diethyl azodicarboxylate (4.07 mL) in 2.5 mL THF. After 18 hours, the reaction was partitioned between 1:1 ethyl acetate:hexane and water, and the organic layer was washed with brine, dried over sodium sulfate, and concentrated. Chromatography of the residue (20% ethyl acetate:hexane) provided 7.05 g (89%) of methyl 2(R)-1-(4-(4-chlorophenoxy)benzenesulfonyl)aziridine-2-carboxylate as a thick syrup.

Step 3. To a stirred solution of methyl 2(R)-1-(4-(4-chlorophenoxy) benzenesulfonyl)aziridine-2-carboxylate (6.81 g) in 13 mL of 2-bromoethanol at 0°C was added dropwise 1.85 mL of boron trifluoride etherate. The reaction was stirred for 30 minutes at 0°C and for 6 hours at room temperature, and then partitioned between 200 mL of 0.1 N pH 7 phosphate buffer and 250 mL of 2:1 ethyl acetate:hexane. The organic layer was washed with water and brine, dried over sodium sulfate, and concentrated. Recrystallization of the residue from t-butyl methyl ether/isooctane gave 3.69 g of a slightly impure solid, which was again recrystallized from t-butyl methyl ether/isooctane to yield 2.35 g of fine white needles. The combined filtrates were concentrated and the residue was chromatographed on 150 g of silica gel with 40% to 50% t-butyl methyl ether in hexane. The product-containing fractions were partially concentrated to ca. 50 mL volume, and the crystalline solid isolated by filtration to provide an additional 1.11 g of product. Total yield of N-(4-(4-chlorophenoxy) benzenesulfonyl)-O-(2-bromoethyl)-D-serine methyl ester was 4.36 g (51%); mp 98°C.

Step 4. To a solution of N-(4-(4-chlorophenoxy)benzenesulfonyl)-O-(2-bromoethyl)-D-serine methyl ester (3.94 g) in 40 mL of anhydrous DMF at 0°C was added 4.0 g of powdered potassium carbonate. After the addition, the ice bath was removed, and the mixture was stirred vigorously as the reaction was allowed to warm to room temperature. After 1 hour, the mixture was partitioned between 200 mL of water and 200 mL of 1:1 ethyl acetate:hexane. The organic layer was washed with 200 mL of 0.1 N pH 7 phosphate buffer, 50 mL of water, and 50

- 77 -

mL of brine, dried over sodium sulfate, and concentrated. The resulting thick syrup (3.86 g) was dissolved in 60 mL of 4:1:1 dioxane:methanol:water at 0°C and 10 mL of 2N aqueous lithium hydroxide was added. The mixture was stirred for 30 minutes at 0°C and then allowed to warm to room temperature. After an additional hour, the reaction was partitioned between 250 mL of 2:1 ethyl acetate:hexane and 100 mL of 0.5 N aqueous sodium bisulfate. The aqueous layer was extracted with an additional 50 mL of ethyl acetate:hexane, and the combined organic layers were washed with brine, dried over sodium sulfate, and concentrated. The residue was chromatographed on 150 g of silica with 70% ethyl acetate:hexane containing 0.5% acetic acid. The product-containing fractions were concentrated to provide 2.98 g (94%) of 3(R)-4-(4-(4-chlorophenoxy)benzenesulfonyl)-morpholine-3-carboxylic acid as a syrup which solidified on standing: mp 161.8°C.

Step 5. To a solution of 3(R)-4-(4-(4-chlorophenoxy)benzenesulfonyl)-morpholine-3-carboxylic acid (3.06 g) in 35 mL of 6:1 dichloromethan:DMF at 0°C was added O-(t-butyldimethylsilyl)-hydroxylamine (1.47 g) followed by EDC hydrochloride (1.77 g). The solution was stirred for 30 min at 0°C and then allowed to warm to room temperature. After 2 hours, the reaction was partitioned between 150 mL of 1:1 ethyl acetate:hexane and 100 mL of water. The organic layer was washed with cold 0.1 N aqueous sodium bisulfate (25 mL), 0.1 N aqueous sodium bicarbonate (25 mL), and brine, dried over sodium sulfate, and concentrated to an oil which solidified upon standing. Trituration with hexane and filtration gave 3.46 g (85%) of 3(R)-N-(t-butyldimethylsilyloxy)-4-(4-(4-chlorophenoxy)benzenesulfonyl)-morpholine-3-carboxamide as a white solid: mp 129.6°C.

Step 6. To a suspension of 3(R)-N-(t-butyldimethylsilyloxy)-4-(4-(4-chlorophenoxy)benzenesulfonyl)-morpholine-3-carboxamide (3.35 g) in 25 mL of methanol at 25°C was added 0.3 mL of trifluoroacetic acid. After 1 hour, 20 mL of toluene was added and the solution was concentrated to a

- 78 -

volume of about 10 mL. Upon addition of an additional 10 mL of toluene, a solid precipitated. After a few minutes, 20 mL of hexane was added and the solid was collected by filtration and dried in vacuo to give 2.65 g (95%) of 3(R)-N-hydroxy-4-(4-(4-chlorophenoxy) benzenesulfonyl)-morpholine-3-carboxamide δ 0.33 toluene as a white solid: mp 104-C. Anal. cal. for $C_{17}H_{17}ClN_2O_6S \cdot 0.33 C_7H_8$: C, 52.32; H, 4.47; N, 6.32; Cl, 8.00; S, 7.23; Found: C, 52.31; H, 4.47; N, 6.26; Cl, 7.97; S, 7.38.

The following compounds can be prepared in similar manner:

(b) 3(R)-N-hydroxy-4-(4-phenoxybenzenesulfonyl)-morpholine-3-carboxamide;

(c) 3(R)-N-hydroxy-4-(4-(4-methoxyphenoxy)benzenesulfonyl)-morpholine-3-carboxamide;

(d) 3(R)-N-hydroxy-4-(4-(pyrid-4-yl)oxybenzenesulfonyl)-morpholine-3-carboxamide;

(e) 3(R)-N-hydroxy-4-(4-(4-fluorophenoxy)benzenesulfonyl)-morpholine-3-carboxamide; and

(f) 3(R)-N-hydroxy-4-(4-(4-(imidazol-2-yl)phenoxy)benzenesulfonyl)-morpholine-3-carboxamide.

Example 9

(a) 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide

Step 1. To a solution of 2(R)-piperazine-2-carboxylic acid (1.30 g) and triethylamine (3.50 mL) in 25 mL of 3:2 acetonitrile:water at -15° C was added BOC-ON (2.70 g) in one portion. The mixture was allowed to warm slowly to 25° C overnight, and then concentrated to a volume of ca. 10 mL. The resulting mixture was partitioned between 25 mL of water and 50 mL of 4:1 ethyl acetate:hexane. The aqueous layer was further washed with dichloromethane (3 x 10 mL) and then concentrated. The semi-solid residue was triturated with ethanol and filtered to give 1.18 g of 2(R)-4-(t-butoxycarbonyl)-piperazine-2-carboxylate. Concentration of the filtrate gave a

- 79 -

second crop of 0.58 g: total yield of 2(R)-4-(t-butoxycarbonyl)-piperazine-2-carboxylic acid was 1.76 g (76%).

Step 2. To a stirred suspension of 2(R)-4-(t-butoxycarbonyl)-piperazine-2-carboxylic acid (4.62 g) and N-methylmorpholine (5.5 mL) in 90 mL of 2:1 dichloromethane:DMF was added dropwise trimethylsilyl chloride (2.79 mL) with cooling in a 15° C water bath. After 1 hour, diisopropylethylamine (3.5 mL) was added and the mixture was stirred for another hour, at which point little solid remained. Additional trimethylsilyl chloride (0.20 mL) was added, and after 30 minutes, the reaction was a homogenous solution, and 4-(4-chlorophenoxy)benzenesulfonyl chloride (6.67 g) was added in one portion. The reaction was stirred for 2 hours, and then quenched with ca. 10 mL of water. After 30 minutes, the mixture was partitioned between 300 mL of 2:1 ethyl acetate:hexane and 100 mL of 0.5 N aqueous sodium bisulfate. The organic layer was washed with 100 mL each of 0.2 N and 0.05 N sodium bisulfate and with 50 mL of brine, dried (sodium sulfate), and concentrated. The residue was purified by chromatography on 200 g of silica, eluting with a gradient of 30% to 40% to 50% ethyl acetate:hexane containing 0.5% acetic acid, to give 9.33 g of 2(R)-4-(t-butoxycarbonyl)-1-(4-(4-chlorophenoxy)-benzenesulfonyl)-piperazine-2-carboxylic acid as a solid foam containing traces of solvent.

Step 3. To a solution of 2(R)-4-(t-butoxycarbonyl)-1-(4-(4-chlorophenoxy) benzenesulfonyl)-piperazine-2-charboxylic acid (995 mg) in 12 mL of dichloromethane at 0°C was added O-(t-butyl-dimethylsilyl)hydroxylamine (430 mg) followed by EDC hydrochloride (460 mg). After 20 minutes, the reaction was allowed to warm to 25°C. After 2 hours, the reaction was partitioned between water and 1:1 ethyl acetate:hexane. The organic layer was washed with water and cold 0.1 N aqueous sodium bisulfate, and finally with pH 7 phosphate buffer/brine. The organic layer was dried over sodium sulfate, and concentrated to a solid. Dissolution in dichloromethane, dilution with isooctane, and partial concentration gave a heavy precipitate, which upon filtration and drying

- 80 -

provided 1.107 g (88%) of 2(R)-N-(t-butyldimethylsilyloxy)-4-(t-butoxycarbonyl)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide: mp 181.6°C.

Anal. calc for $C_{28}H_{40}ClN_3O_7SSi$: C, 53.70; H, 6.44; N, 6.71; S, 5.12; Found: C, 53.79; H, 6.46; N, 6.72; S, 5.19.

Step 4. To a solution of 2(R)-N-(t-butyldimethylsilyloxy)-4-(t-butoxy-carbonyl)-1-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide (100 mg) in methanol (4 mL) was added TFA (0.2 mL). After 1 hour, toluene (20 mL) was added and the solution was concentrated to a solid residue, which was recrystallized from methanol to give 48 mg of 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)-benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide as fine white needles: mp 94.6°C.

The following compounds were prepared in a similar manner:

(b) 2(R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide: mp 151.2°C;

(c) 2(R/S)-N-hydroxy-1-(4-(4-cyanophenoxy)benzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide: mp 131.3°C; and

(d) 2(R/S)-N-hydroxy-1-(4-(pyrid-2-yl)oxybenzenesulfonyl)-4-(t-butoxycarbonyl)-piperazine-2-carboxamide: mp 133.5°C;

Anal. calc. for $C_{21}H_{26}N_4O_7S$: C, 52.71; H, 5.48; N, 11.71; S, 6.70; Found: C, 5.54; H, 5.48; N, 11.61; S, 6.75.

Example 10

(a) 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide hydrochloride

To a solution of 2(R)-N-(t-butyldimethylsilyloxy)-4-(t-butoxy-carbonyl)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide (313 mg) in 7 mL of 6:1 dichloromethane:methanol was added 2.0 mL of 4M

- 81 -

HCl in dioxane. After 1 hour, the solution was partially concentrated to ca. 2 mL, diluted with 5 mL of ethyl acetate, and reconcentrated to near dryness. The residue was triturated with ethyl acetate, filtered, and dried in vacuo to provide 198 mg (88%) of 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide hydrochloride as a white solid: mp 169°C.

Anal. calc. for $C_{17}H_{19}Cl_2N_3O_5S$: C, 45.54; H, 4.27; N, 9.37; Cl, 15.82; S, 7.15; Found: C, 45.59; H, 4.25; N, 9.20; Cl, 15.66; S, 7.02.

The following compound was prepared in a similar manner:

(b) 2(R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide hydrochloride: mp 150.8°C.

The following compounds can be prepared in a similar manner:

(c) 2(R)-N-hydroxy-1-(4-(4-methoxyphenoxy)benzenesulfonyl)-piperazine-2-carboxamide hydrochloride;

(d) 2(R)-N-hydroxy-1-(4-(4-methylphenoxy)benzenesulfonyl)-piperazine-2-carboxamide hydrochloride; and

(e) 2(R)-N-hydroxy-1-(4-(pyrazol-3-yl)benzenesulfonyl)-piperazine-2-carboxamide hydrochloride.

Example 11

(a) 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-methyl-piperazine-2-carboxamide hydrochloride

To a solution of 313 mg of 2(R)-N-(t-butyldimethylsilyloxy)-4-(t-butoxycarbonyl)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide in 2 mL of dichloromethane was added 1 mL of trifluoroacetic acid. After 2 hours, 2 mL of methanol was added and the solution was stirred for 15 minutes and then diluted with 5 mL of toluene. Concentration gave an oily residue, which partitioned between brine/saturated sodium bicarbonate and ethyl acetate. The aqueous layer was extracted with two additional portions of ethyl acetate, and the combined organic layers were

- 82 -

dried over sodium sulfate and concentrated to give 231 mg of slightly impure 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide. To a solution of 186 mg of this solid and diisopropylethylamine (0.15 mL) in 3.5 mL of 6:1 acetonitrile:DMF was added iodomethane (0.031 mL). After 1.5 hours at 25°C, the reaction was diluted with ca. 5 mL of ethyl acetate and concentrated. The residue was partitioned between 0.5 M aqueous sodium bicarbonate and ethyl acetate. The aqueous phase was extracted with a second portion of ethyl acetate, and the combined organic layers were washed with brine, dried over sodium sulfate, and concentrated. The residue was chromatographed on 10 g of silica gel, eluting with gradient of 6% to 8% to 10% methanol in dichloromethane. The product-containing fractions were concentrated, and the residue was dissolved in 5 mL of ethyl acetate:dichloromethane (4:1). To this solution was added 0.4 mL of 1 M HCl in ethanol, and the mixture was concentrated to a white residue, which was triturated with ethyl acetate and filtered to give 115 mg of 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-methyl-piperazine-2-carboxamide hydrochloride as a white solid: mp 152°C (decomp).

Anal. calc. for $C_{18}H_{21}Cl_2N_3O_5S$: C, 46.76; H, 4.58; N, 9.09; Cl, 15.34; S, 6.93; Found: C, 46.65; H, 4.65; N, 8.98; Cl, 15.18; S, 6.84.

The following compounds were prepared in a similar manner:

(b) 2(R)-N-hydroxy-1-(4-phenoxybenzenesulfonyl)-4-methyl-piperazine-2-carboxamide: mp 127.7°C;

Anal. calc. for $C_{18}H_{21}N_3O_5S \cdot 0.5$ hexane: C, 56.71; H, 5.98; N, 10.18;

Found: C, 56.70; H, 5.99; N, 10.05;

- 83 -

(c) 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(ethoxycarbonylmethyl)-piperazine-2-carboxamide hydrochloride: mp 163.7°C;

Anal. calc. for $C_{21}H_{25}Cl_2N_3O_7S$: C, 47.20; H, 4.72; N, 7.86; S, 6.00;

Found: C, 47.09; H, 4.77; N, 7.93; S, 5.90; and

(d) 2(R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-4-methyl-piperazine-2-carboxamide;

Anal. calc. for $C_{18}H_{20}FN_3O_5S$: C, 52.80; H, 4.92; N, 10.26; S, 7.83; Found: C, 52.66; H, 4.95; N, 10.01; S, 7.56.

The following compound can be prepared in a similar manner:

(e) 2(R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-4-(cyclopropylmethyl)-piperazine-2-carboxamide hydrochloride.

Example 12

(a) 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide

Step 1. To a suspension of 1.00 g of 2(R)-N-(t-butylidimethylsilyloxy)-4-(t-butoxycarbonyl)-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide in 4 mL of dichloromethane was added 3 mL of trifluoroacetic acid, resulting in a clear solution. After 2 hours at 25°C, the solution was concentrated to near dryness, and the residue was dissolved in 10 mL of methanol. After 10 minutes, the solution was reconstituted, the residual syrup was dissolved in 50 mL of methanol, and ca. 15 mL of IRA-68 weakly basic resin was added. The mixture was stirred gently for 2 hours, and then the resin was removed by filtration. The filtrate was concentrated to a white solid, which was triturated with hot t-butyl methyl ether, and after cooling to -20°C, filtered to provide 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-piperazine-2-carboxamide (0.552 g) as a white solid: mp 147.0°C.

- 84 -

Step 2. To a suspension of 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)-benzenesulfonyl)-piperazine-2-carboxamide (1.03 g) in 20 mL of dichloromethane was added 0.70 mL of triethylamine, 0.41 mL of N-methylmorpholine, and, in a dropwise manner, 0.67 mL of trimethylchlorosilane. After 1.5 hours, the mixture was cooled to 0°C and methanesulfonyl chloride (0.20) was added dropwise. The mixture was stirred for 30 minutes at 0°C and then allowed to warm to 25°C. After an additional 45 minutes, the mixture was partitioned between 12.5 mL of 4:1 ethyl acetate:hexane and 50 mL of 0.2 M aqueous sodium bisulfate. The organic layer was washed with an additional 50 mL of aqueous sodium bisulfate, and then with 2.5 mL of 1 M phosphate buffer (pH 7) and finally with brine. The organic layer was dried over sodium sulfate and concentrated, and the residue was purified by chromatography (75 g of silica gel, eluting with 40% to 50% ethyl acetate:dichloromethane containing 1% acetic acid). First to elute were several mixed fractions, followed by pure product fractions, which were pooled and concentrated. The residue was re-concentrated from toluene (to remove residual acetic acid), and finally from dichloromethane:t-butyl methyl ether to give a white solid. Trituration with 2:1 t-butyl methyl ether:hexane (ca. 15 mL) and filtration gave 2(R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide (0.646 g) as a white powder.

Anal. Calcd for $C_{18}H_{20}ClN_3O_7S_2 \cdot 0.35$ hexane: C, 46.41; H, 4.83; N, 8.08; S, 12.33. Found: C, 46.43; H, 4.93; N, 8.04; S, 12.25.

The following compounds were prepared in a similar manner:

(b) 2 R)-N-hydroxy-1-(4-(4-fluorophenoxy)benzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide: mp 102.5°C.

;(c) 2 (R/S)-N-hydroxy-1-(4-(4-methoxyphenoxy)benzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide

Anal. calc. for $C_{19}H_{32}N_3O_8S_2$: C, 47.00; H, 4.78; N, 8.65; S, 13.21; Found: C, 47.09; H, 4.81; N, 8.57; S, 13.11.

(d) 2 (R)-N-hydroxy-1-(4-(4-chlorophenoxy)benzenesulfonyl)-4-(1-methylimidazole-4-sulfonyl)-piperazine-2-carboxamide:

mp 186 °C (decomp); ¹H NMR (DMSO-d₆): δ 9.05 (br s, 1H), 7.9-7.7 (m, 4H), 7.57 (dd, J = 2, 6.6 Hz, 2H), 7.24 (dd, J = 2, 6.6 Hz, 2H), 7.15 (d, J = 6.6, 2H), 4.47 (s, 1H), 3.85 (d, J = 12 Hz, 1H), 3.77 (s, 3H), 3.75-3.35 (m, 3H), 2.45 (dd, J = 4.4, 12.5 Hz, 1H), 2.25-2.16 (m, 1H). Anal. calc. for C₂₁H₂₂N₅O₇S₂Cl•0.5H₂O: C, 44.64; H, 4.10; N, 12.40; S, 11.35. Found: C, 44.57; H, 4.08; N, 12.39; S, 11.37.

The following compounds can be prepared in a similar manner:

(e) 2(R)-N-hydroxy-1-(4-(pyrid-4-yl)oxybenzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide;

(f) 2(R)-N-hydroxy-1-(4-(4-(pyrazol-3-yl)phenoxy)benzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide; and

(g) 2(R)-N-hydroxy-1-(4-(4-(imidazol-2-yl)phenoxy)benzenesulfonyl)-4-(methanesulfonyl)-piperazine-2-carboxamide.

Example 13

(a) 3(R/S)-N-hydroxy-4-(4-bromophenoxybenzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide.

Step 1. To a solution of t-butyl-1,2-dibromopropionate (J.C.S. *Perkin I*, p. 1321 (1973); 10.85 g, 37.7 mmol) in chloroform (28 mL) and benzene (20 mL) was added a hot solution of 2-mercaptoethylamine (2.9 g, 37.7 mmol) in chloroform, benzene and triethylamine (11 mL, 79 mmol). This mixture was stirred for 3 days after which it was washed with water and brine. The organic phase was dried (Na₂SO₄), evaporated, and the remaining oil chromatographed on silica (1:1 ethyl acetate/hexane) to give tert-butyl 3(R/S)-tetrahydro-2H-1,4-thiazine-3-carboxylate.

- 86 -

Anal. calc. for $C_9H_{17}NO_2S$: C, 53.17; H, 8.43; N, 6.89; S, 15.77;
Found: C, 53.30; H, 8.41; N, 6.96; S, 15.85.

Step 2. A solution of tert-butyl tetrahydro-2H-1,4-thiazine-3-carboxylate (1.02 g, 5 mmol), 4-(4-bromophenoxy)benzenesulfonyl chloride (1.58 g, 5 mmol), and triethylamine (0.84 mL, 6 mmol) in methylene chloride (10 mL) was stirred at room temperature for 20 hours after which it was diluted with methylene chloride and washed with 3 N HCl. The organic phase was dried (Na_2SO_4) and the solvent evaporated. The remaining orange residue was purified by silica gel chromatography (25% ethyl acetate/hexane) to give t-butyl 3(R/S)-4-(4-(4-bromophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxylate.

Anal. calc. for $C_{21}H_{24}NO_5S_2Br$: C, 49.03; H, 4.70; N, 2.72; Br, 15.53;

Found: C, 48.94; H, 4.67; N, 2.76; Br, 15.62.

Step 3. A solution of t-butyl 3(R/S)-4-(4-(4-bromophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxylate (0.5 g, 0.97 mmol) and trifluoroacetic acid (0.5 mL) in methylene chloride (11 mL) was stirred at room temperature for 1 hour, after which it was concentrated to give 3(R/S)-4-(4-(4-bromophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxylic acid, which was used in the next step without further purification.

Step 4. To a solution of 3(R/S)-4-(4-(4-bromophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxylic acid (0.62 g, 1.4 mmol) and O-t-butyl dimethylsilyl hydroxylamine (0.27 g, 1.8 mmol) in 6 mL of 5:1 dichloromethane:DMF at 0°C was added EDC (0.52 g, 2.6 mmol). The mixture was stirred at 0°C for 30 minutes and at room temperature for 22 hours and then partitioned between ethyl acetate and water. The organic phase was washed with brine, dried (Na_2SO_4), and concentrated. Purification of the residue by chromatography provided 3(R/S)-N-(t-butyl dimethylsilyl)oxy-4-(4-(4-bromophenoxy)-benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide.

- 87 -

Step 5. A solution of 3(R/S)-N-(t-butyldimethylsilyl)oxy-4-(4-(4-bromophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide (0.3 g, 0.51 mmol), trifluoroacetic acid (2.5 ml), and methanol (5.5 mL) in methylene chloride (10 mL) was stirred at room temperature for 1 hour. The solvents were evaporated to leave a solid residue which was washed onto filter paper with ether to give 3(R/S)-N-hydroxy-4-(4-(4-bromophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide.

Anal. calc. for $C_{17}H_{17}N_2O_5Br$: C, 43.14; H, 3.62; N, 5.92; S, 13.55; Found: C, 43.21; H, 3.66; N, 5.83; S, 13.45.

The following compounds were prepared in a similar manner:

(b) 3(R/S)-N-hydroxy-4-(4-phenoxybenzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide;

Anal. calc. for $C_{17}H_{18}N_2O_5S_2$: C, 51.76; H, 4.60; N, 7.10; S, 16.26; Found: C, 51.81; H, 4.56; N, 7.17; S, 16.18; and

(c) 3(R/S)-N-hydroxy-4-(4-(4-fluorophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide;

Anal. calc. for $C_{17}H_{17}N_2O_5Br$: C, 49.50; H, 4.15; N, 6.79; S, 15.55; Found: C, 49.40; H, 4.12; N, 6.72; S, 15.48.

Example 14

(a) 1(R/S),3(R/S)-N-hydroxy-1-oxo-4-(4-(4-bromophenoxy)benzene-sulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide.

Step 1. A solution of t-butyl 3(R/S)-4-(4-(4-bromophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxylate (0.3 g, 0.38 mmol) and sodium perborate (0.11 g, 0.73 mmol) in acetic acid (3 mL) was stirred at 35°C for 5 hours, after which it was quenched with saturated aqueous sodium bicarbonate and extracted with ethyl acetate. The organic layer was dried (Na_2SO_4) and concentrated to give a foam which was purified by silica gel chromatography (ethyl acetate) to give t-butyl 1(R/S),3(R/S)-4-(4-(4-

- 88 -

bromophenoxy)-benzenesulfonyl)-1-oxo-tetrahydro-2H-1,4-thiazine-3-carboxylate: MS (FAB) found 530 (M+H)⁺.

Step 2. To a solution of t-butyl 1(R/S),3(R/S)-4-(4-(4-bromophenoxy)-benzenesulfonyl)-1-oxo-tetrahydro-2H-1,4-thiazine-3-carboxylate (0.18 g, 0.34 mmol) in methylene chloride (4 mL) was added 1.8 mL of trifluoroacetic acid. After 4 hours, the solution was concentrated to give 1(R/S),3(R/S)-4-(4-(4-bromophenoxy) benzenesulfonyl)-1-oxo-tetrahydro-2H-1,4-thiazine-3-carboxylic acid, which was used without further purification.

Step 3. To a solution of 1(R/S),3(R/S)-4-(4-(4-bromophenoxy)benzene-sulfonyl)-1-oxo-tetrahydro-2H-1,4-thiazine-3-carboxylic acid (0.08 g, 0.17 mmol) and O-t-butyldimethylsilyl hydroxylamine (0.037 g, 0.25 mmol) in 6:1 dichloromethane:DMF (3.5 mL) at 0°C was added EDC (0.06 g, 0.34 mmol). The mixture was stirred at 0°C for 30 minutes followed by room temperature for 3.5 hours and then partitioned between ethyl acetate and water. The organic phase was washed with brine, dried (Na₂SO₄) and concentrated. The residue was purified by chromatography (ethyl acetate) to give 1(R/S),3(R/S)-N-(t-butyl-dimethylsilyl)-oxy-1-oxo-4-(4-(4-bromophenoxy) benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide.

Step 4. A solution of 1(R/S),3(R/S)-N-(t-butyldimethylsilyl)oxy-1-oxo-4-(4-(4-bromophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide (0.069 g, 0.11 mmol) and trifluoroacetic acid (0.5 ml) in 2 mL of 1:1 methanol:methylene chloride was stirred at room temperature for 1 hour. The solvents were evaporated to leave a solid residue which was washed onto filter paper with ether and hexane to give 1(R/S),3(R/S)-N-hydroxy-1-oxo-4-(4-(4-bromophenoxy)benzenesulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide.

Anal. calc. for C₁₇H₁₇N₂O₆S₂Br: C, 41.72; H, 3.50; N, 5.72; S, 13.10; Br, 16.33;

Found: C, 41.81; H, 3.46; N, 5.65; S, 13.01; Br, 16.44.

- 89 -

The following compound was prepared in a similar manner:

(b) 1(R/S),3(R/S)-N-hydroxy-1-oxo-4-(4-(4-fluorophenoxy)benzene-sulfonyl)-tetrahydro-2H-1,4-thiazine-3-carboxamide;

Anal. calc. for $C_{17}N_2O_6S_2F$: C, 47.66; H, 4.00; N, 6.54; S, 14.97; Found: C, 47.70; H, 4.09; N, 6.45; S, 14.86.

Example 15

(a) 6(R)-(N-hydroxycarbamoyl)-1-(4-phenoxy)benzenesulfonyl-tetrahydropyrimidin-4-one

Step 1. To a solution of D-asparagine (15.0 g) in 400 mL of water at 45°C was added 8.25 mL of 37% formalin. After 1 hour at 45°C, the solution was cooled to -5°C to give a slurry. The slurry was allowed to warm to 0°C, and the precipitate collected by filtration to give, following drying in vacuo, 2.26 g of 6(R)-carboxy-tetra-hydropyrimidin-4-one as a white crystalline solid: 1H NMR (D_2O , 300 MHz) δ 4.70 and 4.58 (AB quartet, 2H, $J = 11$ Hz), 4.22 (dd, 1H, $J = 6$ and 9 Hz), 3.04 (dd, 1H, $J = 6$ and 16 Hz), 2.82 (dd, 1H, $J = 9$ and 16 Hz).

Step 2. To a solution of 6(R)-carboxy-tetrahydropyrimidin-4-one in 8 mL of water and 4 mL of dioxane was added 1.5 mL of N-methyl-morpholine, followed by a solution of 4-phenoxybenzenesulfonyl chloride (1.88 g) in 4 mL of dioxane. The mixture was stirred for 6 hours and then poured into pH 4.0 citrate buffer and extracted with ethyl acetate (2 x 50 mL). The organic layer was dried over sodium sulfate and concentrated, and the residue chromatographed (15% methanol in dichloromethane containing 1% acetic acid) to give R-carboxy-1-(4-phenoxy)benzenesulfonyl-tetrahydropyrimidin-4-one as a white solid: 1H NMR (D_2O , 300 MHz) δ 7.86 (d, 2H, $J = 9$ Hz), 7.48 (t, 2H, $J = 8$ Hz), 7.29 (t, 1H, $J = 7$ Hz), 7.11-7.18 (m, 4H), 5.03 (d, 1H, $J = 14$ Hz), 4.68 (d, 1H, $J = 14$ Hz), 4.31 (t, 1H, $J = 7$ Hz), 2.68 (dd, 1H, $J = 17$ and 7 Hz), 2.47 (dd, 1H, $J = 17$ and 8 Hz).

Step 3. To a solution of 215 mg of 6(R)-carboxy-1-(4-phenoxy)benzenesulfonyl-tetrahydro-pyrimidin-4-one in 5.5 mL of 10:1

- 90 -

dichloromethane:DMF was added O-(t-butyldimethylsilyl) hydroxylamine (126 mg) followed by EDC hydrochloride (131 mg). After 4 hours, the reaction was partitioned between 1:1 ethyl acetate:hexane and aqueous sodium bicarbonate. The organic layer was dried over sodium sulfate, concentrated, and the residue was rapidly chromatographed with 20% ethyl acetate in dichloromethane to give 6(R)-(N-(t-butyldimethylsilyl)oxycarbamoyl)-1-(4-phenoxy) benzenesulfonyl-tetrahydropyrimidin-4-one as a solid, which, without further purification, was dissolved in 5 mL of methanol and 0.2 mL of trifluoroacetic acid. After 1 hour, 5 mL of toluene was added and the solution was concentrated. The residue was purified by rotary chromatography (65:20:15 dichloromethane:ethyl acetate:ethanol containing 0.5% acetic acid) to give 6(R)-(N-hydroxycarbamoyl)-1-(4-phenoxy)benzenesulfonyl-tetrahydropyrimidin-4-one (31 mg) as a white solid: ^1H NMR (methanol- d_4 , 300 MHz) δ 7.90 (d, 2H, J = 9 Hz), 7.47 (t, 2H, J = 8.7 Hz), 7.27 (t, 1H, J = 7 Hz), 7.09-7.16 (m, 4H), 5.02 (d, 1H, J = 14 Hz), 4.80 (d, 1H, J = 14 Hz), 4.37 (t, 1H, J = 7 Hz), 2.77 (dd, 1H, J = 17 and 7 Hz), 2.72 (dd, 1H, J = 17 and 8 Hz).

The following compound was prepared in a similar manner:

(b) 6(R)-(N-hydroxycarbamoyl)-1-(4-(4-fluorophenoxy)benzene-sulfonyl)-tetrahydropyrimidin-4-one;

Anal. calc. for $\text{C}_{17}\text{H}_{16}\text{FN}_3\text{O}_6\text{S}$: C, 49.87; H, 3.94; N, 10.26; S, 7.83; Found: C, 49.84; H, 3.95; N, 10.18; S, 7.73;

The following compounds can be prepared in a similar manner:

(c) 6(R)-(N-hydroxycarbamoyl)-1-(4-(4-chlorophenoxy)benzene-sulfonyl)-tetrahydropyrimidin-4-one;

(d) 6(R)-(N-hydroxycarbamoyl)-1-(4-(4-methoxyphenoxy)benzene-sulfonyl)-tetrahydropyrimidin-4-one; and

(e) 6(R)-(N-hydroxycarbamoyl)-1-(4-(4-(fur-2-yl)phenoxy)-benzenesulfonyl)-tetrahydropyrimidin-4-one.

Example 16**(a) 3(S)-N-hydroxy-4-(4-(4-bromophenoxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide**

Step 1. A suspension of D-penicillamine (0.5 g, 3.35 mmol) in methanol was cooled to 0°C and powdered sodium hydroxide (0.28 g, 7.04 mmol) was added in one portion to give a colorless solution. 2-Bromo-ethanol (0.24 mL, 3.35 mmol) was added and the reaction mixture stirred at 0°C for 25 minutes and room temperature for an additional 80 minutes. The solvent was evaporated and the solid residue was treated with water, brought to pH 3 with 6N HCl and reconcentrated. The resulting oily residue was dissolved in water (6 mL) and stirred with DMF, sodium carbonate (1.17 g, 11.04 mmol) and 4-(4-bromophenoxy)benzenesulfonyl chloride (1.28 g, 3.68 mmol) for 17 hours. The solution was diluted with water and washed with ethyl acetate. The aqueous layer was acidified to pH 1.5 with concentrated HCl and extracted with ethyl acetate. The organic extracts were combined, washed with water and brine and dried. The solution was filtered, evaporated and azeotroped from benzene to give the crude acid as a viscous oil (0.807 g; 48% yield).

Step 2. A portion of this oil was dissolved in DMA (3 mL), treated with potassium carbonate (2.4 g, 17.5 mmol), benzyltriethylammonium chloride (0.15 g, 0.67 mmol) and t-butyl bromide (3.7 mL, 32 mmol). The reaction mixture was stirred vigorously for 18.5 hours at 55°C, after which it was diluted with ethyl acetate, washed with water, dried and evaporated to give a viscous oil which was purified by silica gel chromatography (50% ethyl acetate:hexane) to give 2(S)-3-(2-hydroxyethylsulfany1)-3-methyl-2-(4-(4-bromophenoxy)-benzenesulfonylamino)-butyric acid tert-butyl ester as a colorless, viscous glass.

Anal. calc. for $C_{23}H_{30}NO_6S_2Br$: C, 49.28; H, 5.39; N, 2.50; S, 11.44; Br, 14.25;

Found: C, 49.21; H, 5.25; N, 2.46; S, 11.37; Br, 14.31.

Step 3. To a solution of 2(S)-3-(2-hydroxyethylsulfany1)-3-methyl-2-(4-(4-bromophenoxy)benzenesulfonylamino)-butyric acid tert-butyl ester (0.17 g,

- 92 -

0.30 mmol) in THF (5 mL) was added triphenylphosphine (0.102 g, 0.39 mmol) and diethylazodicarboxylate (0.61 mL, 0.39 mmol). After stirring at room temperature for 20 minutes, the solvent was evaporated and the product purified on silica gel (40% ethyl acetate:hexane) to give tert-butyl 3(S)-4-(4-(4-bromophenoxy)-benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate as a light yellow oil.

Anal. calc. for $C_{23}H_{28}NO_5S_2Br$: C, 50.92; H, 5.20; N, 2.50; S, 11.82;

Found: C, 51.03; H, 5.18; N, 2.95; S, 11.33.

Step 4. A solution of tert-butyl 3(S)-4-(4-(4-bromophenoxy)-benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylate (0.12 g, 0.22 mmol) in dichloromethane (2 mL) and TFA (1 mL) was stirred at room temperature for 50 minutes, after which the solvents were evaporated and the residue azeotroped from benzene to give 3(S)-4-(4-(4-bromophenoxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid as a white solid, which was next used without further purification.

Step 5. A solution of 3(S)-4-(4-(4-bromophenoxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxylic acid (0.11 g, 0.22 mmol), O-t-butyl dimethylsilyl hydroxylamine (0.049 g, 0.33 mmol) and EDC (0.085 g, 0.44 mmol) in dichloromethane (2 mL) was stirred at room temperature for 30 minutes, after which the reaction mixture was diluted with dichloromethane (30 mL), washed with 5% citric acid and saturated sodium bicarbonate, dried and evaporated to give crude 3(S)-N-(t-butyl dimethylsilyl)oxy-4-(4-(4-bromophenoxy)-benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide, which was next used without further purification.

Step 6. A solution of 3(S)-N-(t-butyl dimethylsilyl)oxy-4-(4-(4-bromophenoxy)benzenesulfonyl)-2,2-dimethyl-tetrahydro-2H-1,4-thiazine-3-carboxamide (0.12 g, 0.19 mmol) and trifluoroacetic acid (2 mL) in dichloromethane (2 mL) was stirred at room temperature for 1 hour, after which the solvents were evaporated and the residue was azeotroped from benzene. The product was triturated with diethyl ether, filtered and washed